Quantification of springbok (*Antidorcas marsupialis*) meat yield and meat quality

by

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DECLARATION

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Date: March 2020

SUMMARY

This study aimed to determine the effect of subspecies, sex and intensity of culling on the meat yield and meat quality of springbok (*Antidorcas marsupialis*). This was done by analysing data on the carcass yield, carcass composition and the physical and chemical meat quality of selected muscles. A number of game ranchers have started to use Damara (*Antidorcas marsupialis angolensis)* rams with their Karoo *(Antidorcas marsupialis marsupialis*) ewes in their breeding programs, in the hope that the progeny of this hybridisation would be larger than the Karoo subspecies parent. This started after speculation arose that the entire Damara subspecies is larger than the Karoo subspecies and would be an ideal choice to breed with the Karoo springbok where the thought that the intensive culling for size amongst the latter, has led to smaller animals. Therefore, baseline data is necessary to evaluate the influence of subspecies (Damara vs Karoo) and intensity of culling on the meat yield and meat quality of springbok.

Trial 1 consisted of twenty Damara springbok from the north of Namibia and twenty Karoo springbok from Wellington in the western cape of South Africa. The Damara subspecies (43.37±0.869 kg males, 36.59±0.923 female) had significantly heavier dead weights in comparison to the Karoo springbok (32.04±0.868 males, 26.81±0.660 females). Deadweight and carcass weight also differed between sexes, where male springbok had heavier dead weights and carcass weights. Damara (57.91±0.643 % males, 54.24±0.680 % females) and Karoo (57.66±0.988 % males, 54.28±0.740 % females) springbok exhibited sexual dimorphism for dressing percentage. Trial 2 consisted of the same twenty Karoo springbok from Wellington (low intensity) and an additional twenty springbok from Witsand, where male springbok has been intensively culled for the last decade. Wellington male springbok had heavier dead weights and cold carcass weights than Witsand male springbok, whereas females from the two farms had similar dead weights and carcass. The differences in body weight observed between Damara and Karoo subspecies have economic implications when animals are paid per carcass weight whilst the intensity of over-culling affects linear body measurements and yields of particularly male springbok compared to female springbok, as has been typically reported for the selectively culled sex.

The proportional composition of a carcass is economically important and can be utilised for increased meat production and the utilising of certain breed's naturally superior composition. The Damara springbok had a proportionally smaller shoulder than the Karoo springbok, but subspecies had no effect on the rest of the carcass proportion, nor did

subspecies influence the meat, bone or fat percentage. Sex, however, did influence the proportional composition, where females had a higher percentage of hindquarter and males a proportionally larger forequarter. Female springbok also had a higher fat percentage than males and subsequently a lower lean meat yield (Trial 1). The intensity of culling yielded Wellington (low intensity) springbok that had a higher percentage contribution for the forelimb and ventral trunk in comparison to Witsand springbok (high intensity). The Wellington springbok also had higher meat and lower bone composition for the forelimb and ventral trunk than the Witsand springbok (Trial 2), as has been typically reported for younger animals.

Damara and male springbok also had a higher Warner-Braztler shear force (WBSF) and cooking loss in comparison to the Karoo and female springbok. Consequently, the Damara springbok had less tender meat, although both subspecies had a WBSF mean that was <33N, and as such could be classified as very tender. The Karoo subspecies had higher L*, a*, b*, and chroma meat colour ordinates in comparison to the Damara subspecies making the Karoo meat lighter, redder, and more vivid (saturated). Physical meat quality differences between subspecies were not necessarily large enough for one subspecies to be beneficial over the other. The intensity of culling trial yielded few differences between Wellington (low intensity) and Witsand (high intensity) springbok for physical meat quality (Trial 2). Thus, the high intensity of culling did not influence the physical meat quality characteristics of springbok when sufficient time has progressed between culls, and the animals have had time to replenish their glycogen reserves.

The chemical composition of the Damara and Karoo subspecies meat was also determined where the Damara and Karoo subspecies did not differ for any of the chemical components. Female springbok had a higher intramuscular fat (IMF) content than male springbok, although sex did not affect any other chemical components. The chemical composition of springbok meat was marginally affected by sex, irrespective of subspecies.

Subspecies influences the dead weight, carcass weight and all primal weights. But subspecies did not differ drastically for any proportional parameter. Subspecies also did not influence the physical and chemical meat quality to an extent that would negatively influence the perception of a subspecies' meat. Thus, game ranchers can utilise either subspecies without negative quality repercussions

A high intensity of culling influences the dead weight and carcass weight of the selectively culled sex, this means that a high intensity of culling within a herd will ultimately decrease the size of the males culled over time.

OPSOMMING

Die doel van hierdie studie was om die effek van subspesie (Damara vs Karoo), geslag en intensiteit van uitdunning op die vleisopbrengs en vleis gehalte van springbok (*Antidorcas marsupialis*) te bepaal. Hierdie was verrig deur die analise van data wat versamel is oor die karkas opbrengs, karkas samestelling, vleis kwaliteit en chemiese samestelling van springbok vleis. Daar is tans `n toename in boere wat Damara (*Antidorcas marsupialis angolensis)* ramme gebruik om die Karoo *(Antidorcas marsupialis marsupialis*) ooie in hul teel programme te dek. Hierdie word gedoen in die hoop dat die nageslag van die Damara en Karoo kruis, groter sal wees as hul Karoo ouer. Die praktyk het begin nadat daar vermoed is dat die Damara subspesies heelwat groter as die Karoo subspesie is, ter selfde tyd glo boere ook dat oor tyd het die grootte van die Karoo springbokke afgeneem as gevolg van selektiewe oes van groot diere. Grondslag data word dus benodig om die invloed van subspesie, geslag en intensiteit van oes op die vleisopbrengs en vleis kwaliteit van springbokke te bepaal.

Proef 1 het bestaan uit twintig Damara springbokke vanuit die noorde van Namibia en twintig Karoo springbokke wat verkry is in Wellington. Die Damara subspesie (43.37±0.869 kg manlik, 36.59±0.923 vroulik) was merkbaar swaarder as die Karoo (32.04±0.868 manlik, 26.81±0.660 vroulik) subspesie. Die dooie gewig en koue karkas gewigte het merkbaar verskil tussen die geslagte, waar die manlike diere swaarder was. Die manlike diere het ook `n hoër uitslag persentasie gehad in vergelyking met die vroulike springbokke. Proef 2 het bestaan uit dieselfde twintig Karoo springbokke vanuit Wellington en dan nog twintig Karoo springbokke wat verkry is vanuit Witsand. Daar is al vir die laaste dekade intensief selektief groot ramme ge-oes op die Witsand plaas. Die Wellington-manlike springbokke was swaarder as die Witsand-manlike springbokke, terwyl die vroulike springbokke van beide plase nie van mekaar af verskil het nie. Die verskille in dooie gewig en koue karkas gewig tussen die subspesies het ekonomiese gevolge wanneer diere per karkasgewig betaal word, terwyl die intensiteit van oes lineêre liggaamsmetings en dus liggaamsgewig van veral manlike diere beïnvloed.

Die proporsionele samestelling van `n karkas is van ekonomiese belang aangesien dit benut kan word om potensiële verhoogde vleis opbrengs te bepaal, deur die benutting van `n spesie se genetiese potensiaal. Die Damara springbokke het `n kleiner persentasie skouer gehad, maar verder het subspesie geen invloed gehad op die karkas samestelling nie. Geslag het wel die karkas samestelling beïnvloed, waar vroulike springbokke `n hoër agterkwart persentasie gehad het, terwyl manlike diere `n hoër persentasie voorkwart gehad het (Proef 1). Vroulike sprinbokke het ook ‘n hoër persentasie vet as die manlike springbokke en gevolglik ‘n laer maer vleis opbrengs gehad. Die intensiteit van die uitskot het Wellington (lae intensiteit)

springbokke opgelewer wat 'n hoër persentasie bydrae vir die voor- en ventrale snit gehad het in vergelyking met die Witsand-springbokke (hoë intensiteit). Die Wellington-springbokke het ook 'n hoër samestelling van vleis en laer bene vir die voor- en ventrale snit gehad as die Witsand-springbokke (Proef 2), soos gewoonlik by jonger diere gemeld is.

Damara en manlike springbokke het ook 'n hoër skuifkrag van Warner-Braztler (WBSF) en kookverlies gehad in vergelyking met die Karoo en vroulike springbokke. Gevolglik het die Damara-springbok minder teer vleis gehad, hoewel beide subspesies 'n WBSF-gemiddelde van <33N gehad het, en sodanig as baie sag geklassifiseer kon word. Die Karoo-subspesies het hoër L *, a *, b * en chroma vleiskleur ordinate gehad in vergelyking met die Damara-subspesies wat die Karoo-vleis ligter, meer rooi en meer helder (versadig) maak. Fisiese vleiskwaliteitverskille tussen subspesies was nie noodwendig groot genoeg dat die een subspesie meer voordelig sou wees as die ander nie. Die intensiteit van die uitdun proef het min verskille opgelewer tussen die Wellington (lae intensiteit) en Witsand (hoë intensiteit) springbok vir fisieke vleiskwaliteit (Proef 2). Die hoë intensiteit van uitdunning het dus nie die fisieke vleiskwaliteitseienskappe van springbokke beïnvloed as daar voldoende tyd tussen die uitdunne gevorder het nie, en die diere tyd gehad het om hul glikogeen reserves aan te vul.

Die chemiese samestelling van die Damara- en Karoo-subspesievleis is ook bepaal waar die Damara- en Karoo-subspesie nie verskil het vir enige van die chemiese komponente nie. Die vroulike springbokke het 'n hoër inhoud van die binnespierse vet (IMF) as die manlike springbokke, hoewel geslag geen ander chemiese bestanddele beïnvloed het nie. Die chemiese samestelling van springbokvleis is effens beïnvloed deur geslag, ongeag die subspesie.

Die subspesies beïnvloed die dooie gewig, karkasgewig en alle primêre snit gewigte. Die subspesie het egter nie drasties verskil vir enige proporsionele parameter nie. Die subspesies het ook nie die fisiese en chemiese vleiskwaliteit beïnvloed in 'n mate wat die persepsie van 'n subspesievleis negatief sou beïnvloed nie. Dus kan wildboere van enige subspesie gebruik maak sonder negatiewe gevolge vir die kwaliteit.

‘n Hoë intensiteit van uitskot beïnvloed die dooie gewig en die karkasgewig van die geslag wat selektief uitgedun word. Dit beteken dat 'n hoë intensiteit van uitdunning in 'n kudde die grootte van die mannetjies, wat mettertyd uitgeroei word, sal verminder.

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ABBREVIATIONS

Abbreviation	Expansion
°C	Degrees Celsius
%	Percentage
Φ	Diameter
ANOVA	Analysis of Variance
BF	*Biceps femoris* muscle
CIE	International Commission on Illumination
Cm	Centimetre
DFD	Dark, firm and dry
G	Gram
GIT	Gastro-intestinal tract
Ha	Hectare
IMF	Intramuscular fat
IS	*Infrapsinatus* muscle
Kg	Kilogram
LSMeans	Least square means
LTL	*Longissimus thoracis et lumborum* muscle
Mm	Millimetre
N	Newton
N	Number (Sample size)
pH_u	Ultimate pH
R	Pearson's correlation coefficients
RSA	Republic of South Africa
SM	*Semimembranosus* muscle
SS	*Supraspinatus* muscle
ST	*Semitendinosus* muscle
WHC	Water-holding capacity
WBSF	Warner-Bratzler shear force

NOTES

This thesis is presented in the prescribed format as determined by the Department of Animal Sciences, Stellenbosch University. The language, style and referencing format that was used are as prescribed by the journal of *Meat Science*. This thesis is a compilation of manuscripts in which each chapter is a separate entity, this means that a degree of repartition was unavoidable.

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CHAPTER 1
GENERAL INTRODUCTION

1.1 BACKGROUND

The population of developing countries such as South Africa continues to increase and subsequently, the world population is estimated to reach nine billion by the year 2050 (United Nations, 2019). The constant increase in the global population is a reality that challenges food producers, as food production will need to grow by at least 50 % by 2050 (Ingram, Ericksen, & Liverman, 2010; United Nations, 2019). Protein and micronutrient deficiency are already prevalent in developing countries (Whaley *et al*., 2003) and increased protein production will need to take place within the next few decades. Meat is a source of condensed high-quality proteins that has a high biological value (Williams, 2007). The composition of meat is such that meat is a source of essential minerals and vitamins that can compensate for other dietary shortcomings (Bender, 1992; Williams, 2007; Wu *et al*., 2014). The increasing agricultural output necessary to maintain food self-sufficiency would subsequently increase the water demand of the agricultural industry (Stefanis, 2014).

The various aspects of food security, especially agronomic aspects are all sensitive to climate change (Porter *et al*., 2015). Alternative food security solutions need to be considered (Stefanis, 2014). The South African game industry has continued to grow and contributes significantly to the South African economy (Lindsey *et al*., 2016), but the game industry is still underutilised (Van Schalkwyk & Hoffman, 2016). Game species could play a unique role in the aiding of food security as game species are well adapted to the arid and semi-arid environment and thrive in regions that domestic species cannot (Bothma & Du Toit, 2010). Game species also have a lower water requirement than domestic species and have similar if not more favourable meat production potential in comparison to domestic species as game species have been reported to produce a higher amount of lean meat in veld conditions when compared to cattle (Hopcraft, 1980). Although game meat is not always positively received by consumers, as game meat tends to be perceived as being dry, although this is somewhat attributed to the lack of knowledge on the proper cooking method (Radder & Le Roux, 2005). The game meat industry is also negatively influenced by the lack of uniformity as well as a lack of constant supply of a constant quality (Wassenaar, 2016). Consumers have become increasingly health conscience and most consumer prefer meat with very little visible fat (Ngapo, Braña Varela, & Rubio Lozano, 2017). Game species tend to have a lower intramuscular fat (IMF) and subsequently a higher protein content than that of domestic species (Bureš, Bartoň, Kotrba, & Hakl, 2015; Williams, 2007).

Springbok is an abundant game species and are highly favoured in most if not all game ranches (Furstenburg, 2016; Taylor *et al*., 2016). Springbok are also highly favoured for meat production due to their favourable carcass yield and meat quality (Von la Chevallerie, 1970). There are three different subspecies of springbok, namely the Karoo springbok (*Antidorcas marsupialis marsupialis*), the Kalahari springbok (*Antidorcas marsupialis hofmeyri*) and the Damara springbok (*Antidorcas marsupialis angolensis*) (Skinner, 2005). The Northern subspecies (Damara and Kalahari) have been reported to be larger than the southern subspecies (Karoo) and thus, ranchers have recently started to cross the Northern (Damara and Kalahari) springbok with the Southern (Karoo) in an attempt to produce progeny that are larger than their Karoo parent (Furstenburg, 2016). There is no information available on the meat quality and meat yield of the Damara springbok and as this subspecies is currently being utilised by game ranchers it is important that the effect of subspecies be determined as pertaining to the meat yield and meat quality of the different subspecies of springbok.

The game industry has reported a continued growth and with the hopeful future growth (Taylor *et al*., 2016; The National Agricultural Marketing Council, 2006), some management practices should be taken into account, such as the extensive over-culling of mature male springbok in a herd. The influence of high intensity of selective culling on the carcass yield and meat quality characteristics has yet to be determined.

1.2 RESEARCH QUESTION, AIMS AND OBJECTIVES

The main research question of this study is: Do subspecies, sex and intensity of culling of springbok influence the quantity and quality of springbok meat? This study aimed to determine the difference between subspecies (Damara and Karoo) and sex for yield and quality of springbok meat. This study also aimed to determine the effect of intensity of culling and sex on the yield and quality of springbok meat (only Karoo subspecies). The objectives of this study were as follows:

1. Determine the known differences between subspecies and sex as well as determine the effect of intensive culling on game animals as known in the literature (Chapter 2).
2. Determine the effect of subspecies, sex and intensity of culling on the yield and body measurements of springbok (Chapter 3)
3. Determine the effect of subspecies, sex and intensity of culling on the compositional yield of springbok (Chapter 4)

4. Determine the effect of subspecies, sex and intensity of culling on the physical meat quality of springbok (Chapter 5).
5. Determine the influence of subspecies, sex and intensity of culling on the chemical composition of springbok meat (Chapter 6)

The results of this study will report baseline data for the game industry on the effect of subspecies and intensity of culling on the meat yield and meat quality of springbok.

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CHAPTER 2
LITERATURE REVIEW

2.1 ECONOMIC AND CONSERVATION CONTRIBUTIONS OF THE GAME INDUSTRY

An ever increasing number of farms have switched partially or fully to game ranching (Cloete, Taljaard, & Grové, 2007; Taylor *et al.,* 2016), increasing the estimated area that wild life ranches encompass to approximately 17 million hectares in 2016 (Taylor *et al*., 2016).The true economic benefit of such a switch is still debated as the switch over from domestic species farming to game ranching entails a sizeable capital investment, especially in fencing (Cloete *et al*., 2007). Despite the financial implications of switching to game ranching there has been an annual growth of 5% in game farms (The National Agricultural Marketing Council, 2006). The reason for this change has been largely economic and environmental as vast parts of South Africa are not suitable for crop production. Only 17 % of South Africa's agricultural land can be utilised for crop production (The National Agricultural Marketing Council, 2006) and similarly in Namibia, only 16% of the agricultural land can be utilised for crop production (Namibia Statistics Agency, 2016), leaving eighty three and eighty four percentage respectively suitable only for animal production (The National Agricultural Marketing Council, 2006). Of this approximately eighty percent, vast parts are arid and are not suitable for domestic species. As temperatures rise and climates change, domestic species become less suited to the climate and production of game species or mixed game and domestic species production systems become more prominent (Otieno & Muchapondwa, 2016). Both mixed ranches as well as pure wildlife ranches were prominent in 2016 as 54.4 % of the 251 surveyed farms were only game ranches whereas 40.2% of farms surveyed were mixed production systems that had both wildlife and livestock production activities (Taylor *et al*., 2016). Mixed livestock and game farms are still prominent as they are less susceptible to environmental changes although game ranches have been reported to be more economically feasible (Otieno & Muchapondwa, 2016).

Game species, especially springbok are highly adapted to arid areas (Curry, Hohl, Noakes, & Kohn, 2012), and can utilise vegetation more efficiently and have a better resistance to parasites (Oberem, 2016). Springbok are water independent, but most game species need less water in comparison to domestic species (Bothma & Du Toit, 2010).

The game ranching industry contributes significantly to the economic growth of South Africa (Pitman *et al*., 2017), and is made up of four pillar components. These components are namely trophy hunting, breeding (live sales), ecotourism and processed products (Van der

Merwe, Saayman, & Krugell, 2004). Although obtaining up to date data is challenging, an estimated 225 000 animals were sold at auction, 130 000 were hunted for trophies and 277 000 were hunted for biltong in 2016 (Taylor *et al*., 2016). Trophy hunting and biltong hunting has been estimated to have generated R2 billion in 2016 (Figure 2.1) (Taylor *et al*., 2016). Whereas lives sales on its own reported an estimated revenue of R2.5 billion in 2016 (Taylor *et al*., 2016). Live sales and culling for higher quality meat sales has been suggested to be more economically important than trophy hunting (Berry, 1986). The wildlife ranching sector has the potential to contribute significantly to the economy, job creation and thus alleviation of poverty, especially when compared to livestock production which competes for the same resources (Cloete & Rosouw, 2014).

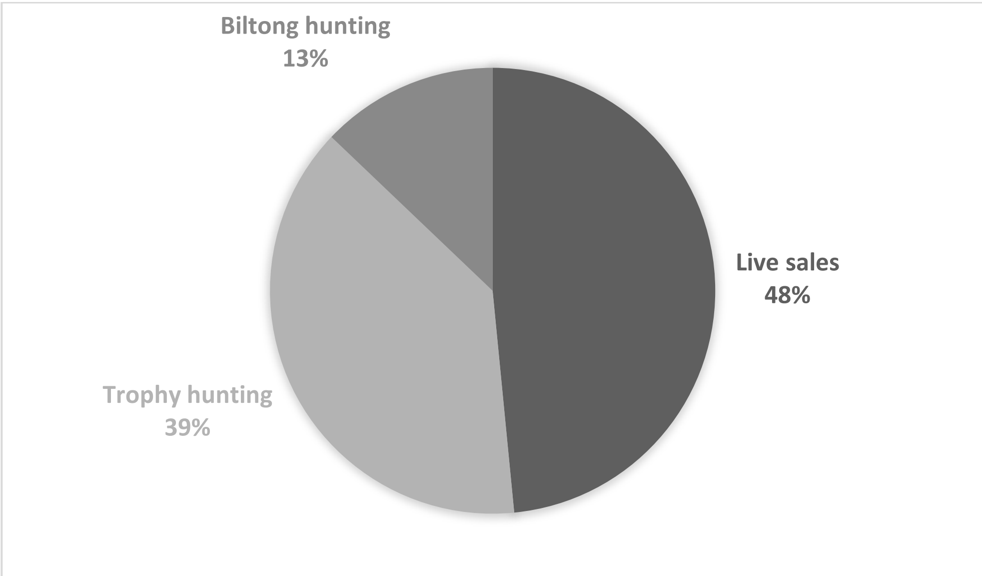

Figure 2.1: The Illustrated proportional financial gain per game ranching sector (Taylor *et al*., 2016)

Springbok is one of the most economically important game species (Taylor *et al*., 2016) and are the most abundant species on game farms (Jooste, 2011) where they are the most sought after game species for biltong hunting and the third most popular species for trophy hunting (Figure 2.2)(Taylor *et al*., 2016). There are currently 1.5 million springbok in South Africa and 730 000 in Namibia (Furstenburg, 2016). The highest occurrence of springbok in South Africa is in the Karoo (Jooste, 2011), where game farms have cropping / hunting focused practices in comparison to the other provinces that have more trophy hunting focused practices (Jooste, 2011).

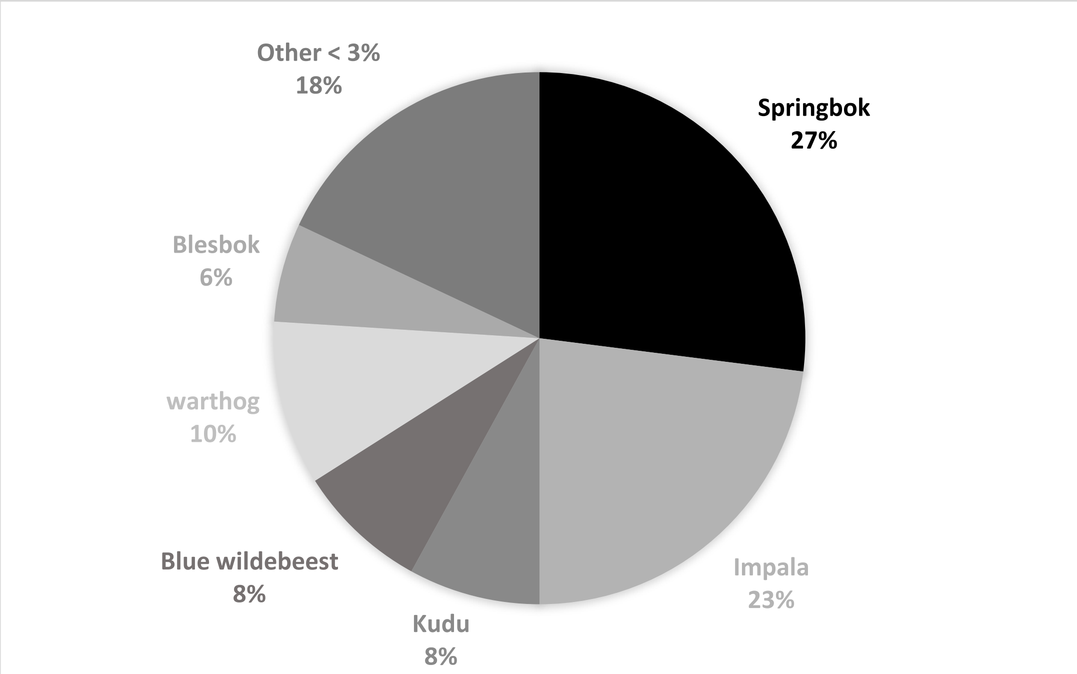

Figure 2.2: Illustration of the percentage animals culled for meat/ biltong per species (adapted from Taylor *et al*., 2016)

Hunting, including trophy and biltong hunting, has been suggested to play an important role in the ability of South Africa to preserve its natural habitats. The financial incentives of game rancher and the subsequent increased conversion of farms to game ranches has increased the country's conservation potential (Lindsey, 2008; Lindsey, Roulet, & Roman, 2007; Taylor *et al*., 2016). This conservation potential is increased by the increased number of game animals as well as the increased diversity of game species, even those that are not hunted (Barnes & De Jager, 1996; Carruthers, 2008; Heffelfinger, Geist, & Wishart, 2013; Lindsey *et al*., 2006). It has also been suggested that effectively managed game farms could not only protect the veld but help restore it (Dlamini & Fraser, 2010). Although there is some dispute on the role of game farms as a conservation tool as it has also been reported that the increase in game ranching, although economically significant, has happened at a cost to conservation (Pitman *et al*., 2017). As the growth of the game industry increases and continues to do so, it is vital that new markets are sought and developed to guard the industry against future collapses as have been seen in the past (Kohn, Kritzinger, Hoffman, & Myburgh, 2005). One such market that has shown promise is the utilisation of game meat into the formal market systems. However, for game meat to enter the formal market, knowledge of the meat production potential (yield, etc.) as well as the meat quality attributes (physical, chemical, etc.) of the various species and subspecies are required.

2.2 INSTRINSIC FACTORS AFFECTING PHYSICAL MEAT QAULITY

Physical meat quality is determined by analytical methods prescribed by Honikel, (1998) and is subdivided into various components, namely the surface colour, Warner-Bratzler shear force, meat acidity (pH) and water-holding capacity (WHC). Water-holding capacity is then further subdivided into cooking loss percentage and drip loss percentage, and when packaged, weep loss percentage. These components form part of a standardised method in which the quality of meat can be compared across studies, ages, sex and species/breeds (Honikel, 1998). The influence of various species and breeds on the physical meat quality has been reported by a variety of studies. The physical meat quality of various species/ breeds are presented in Tables 2.1 and 2.2.

Meat acidity is determined by measuring the pH of meat at different time intervals, where the ultimate pH (pH_u) is the pH measured 24 hours *post mortem* and is the pH that provides a direct indication of the glycogen reserves of the animal at slaughter (Wiklund, Manley, & Littlejohn, 2004). The pH_u is most often used as an indication of physical meat quality as the glycogen reserves of an animal influences the pH_u and thus the other physical meat quality characteristics such as colour, shear force and WHC (Hood & Tarrant, 1982; Wiklund *et al*., 2004). Other pH measurements are often taken such as the pH_{45} (taken 45 minutes *post mortem*), this pH_{45} is used in conjunction with the ultimate pH to determine the rate of the pH decline in the animal (Hoffman, 2000). Both the ultimate pH and the rate of pH decline as well as *post mortem* temperature significantly influences the meat tenderness, surface colour and WHC (Wiklund *et al*., 2004; Yu & Lee, 1986). The ultimate pH of non-stressed animals is ideally between 5.3 – 5.7 and is the resulting pH_u when animals have sufficient glycogen reserves and are in a relatively good condition at slaughter (Briskey & Wismer-Pedersen, 1961; Wiklund, Johansson, & Malmfors, 2003). These pH_u bounds do not necessarily mean that meat outside these bounds cannot be considered as normal non-stressed meat. As is seen in that ultimate pH values of about 5.4 – 6.0.

Ante mortem stress depletes the glycogen reserves prior to slaughter/ cull (Lawrie & Ledward, 2006), and this causes less lactic acid production during the conversion of muscle to meat (via anaerobic glycolysis) and subsequently the pH decline is insufficient and causes abnormal muscle ultimate pH values (Honikel, 2004). Meat of inferior quality, also known as Dark firm and dry (DFD), is thus produced when animals experience *ante mortem* stress (Lawrie & Ledward, 2006; Warris, 2000). DFD meat is often defined as meat with an ultimate pH of ≥ 6, where the pH decline was insufficient to reach a normal ultimate pH due to low glycogen reserves at slaughter (Warris, 2000).

The negative consumer perceptions of game meat quality (Hoffman, Muller, Schutte, Calitz, & Crafford, 2005; Wassenaar, Kempen, & van Eeden, 2019) is often due to the presence of inferior quality meat in the game meat market such as DFD meat (Wassenaar *et al*., 2019). Thus, the negative consumer perception of game meat can be attributed to the larger extent of *ante mortem* stressors that game species can experience during culling. To ensure quality meat that would meet consumer preference culling practices should be considered, as was illustrated when springbok were harvested by making use of an inexperienced culling team and the region in which this team culled had a high incidence of DFD meat (Hoffman, Kroucamp, & Manley, 2007a).The hunting/ culling method has also been reported to have an effect of the ultimate pH and thus meat quality in impala. Day versus night culling was investigated in which night culling causes the least stress (Kritzinger, Hoffman, & Ferreira, 2003). As game species are not slaughtered in a controlled environment (abattoir) as domestic species are, there are more *ante mortem* stressors that need to be considered as these will influence the meat pH_u and thus meat quality (Hoffman, 2000; Kritzinger *et al*., 2003).

Sex has also been reported to influence the ultimate pH of game species. Male springbok are highly territorial during the mating season and actively defend their territories and if cropping takes place during the rut, males will generally have a higher pH_u values than their female counterparts due to their physical activity of defending their territory, which depletes their glycogen reserves (Lewis *et al.,* 1997). However, this was not seen in Karoo springbok from different regions, where males had a lower pH_u than their female counterparts (Hoffman *et al*., 2007a) nor in mountain reedbuck where males and females had similar pH_u values; the mountain reedbuck were not in their mating season (Hoffman, van Schalkwyk, & Muller, 2008). Male impala were reported with a higher pH_u value than female impala, when cropping commenced in the rut season (Hoffman, 2000). Spent male water buffalo also reported a higher pH_u value than spent female buffalo (Kandeepan, Anjaneyulu, Kondaiah, Mendiratta, & Lakshmanan, 2009).

The water holding capacity (WHC) of meat is a measure of the extent to which meat can retain water (Kerry & Ledward, 2009; Warris, 2000). The ultimate pH of 5.4-5.5 is close to the iso-electric point of the meat proteins within the muscle (Huff-Lonergan & Lonergan, 2005), and this iso-electric point is where electrostatic forces are decreased and consequently the myofilament space is decreased, decreasing the ability of meat to retain water (Offer *et al*., 1989; Offer, 1991; Offer & Cousins, 1992). As the ultimate pH of a non-stressed animal is generally between 5.3-5.7, some water loss is unavoidable (Briskey & Wismer-Pedersen, 1961). WHC and pH_u are closely related (Kerry & Ledward, 2009) and a high rate of pH decline combined with a low ultimate pH causes a low WHC in meat and consequently a high moisture loss (Huff-Lonergan & Lonergan, 2005). Moisture loss of meat is either through drip loss/weep or through cooking loss (Warris, 2000). Drip loss is unsightly and negatively influences consumer perception of meat quality (Troy & Kerry, 2010) and cooking loss and juiciness are highly correlated and independent of temperature; a higher cooking loss causes a lower juiciness (Bejerholm & Aaslyng, 2004), once again, negatively influencing consumer perception (Troy & Kerry, 2010).

Carcass sizes has been reported to influence the WHC of meat. After cropping the animals body temperature is ~37°C, after carcasses are dressed the carcass will start to cool. The rate at which the carcass cools depends on the size of the carcass - a larger carcass will cool slower, as well as the fat cover - a thicker fat layer will also slow the chilling process (Warris, 2000). Temperature/rate of chilling can influence the enzymatic degradation (Smulders, 1992). Rate of temperature decline also influences the rate of pH decline. As the rate of pH decline influences the WHC, the rate of cooling can influence the WHC capacity (Warris, 2000).

Sex has also been noted to affect the WHC of meat. North & Hoffman, (2015) as well as Hoffman *et al*. (2007a) reported that mature male springbok had a higher cooking loss than mature female springbok. In contrast, Hoffman, *et al*, (2019) reported on female Namibian springbok with higher cooking losses in comparison to males. Although in the study by Hoffman *et al* (2019) the springbok were classed at a younger age than in other studies. The discrepancy across studies could be due to the differences in ages as well as skewed sex-age ratios of the springbok in the different studies.

Meat tenderness is one of the most important physical attributes to ensure consumer acceptability (Troy & Kerry, 2010). Consumers are willing to pay more if meat is of high quality, the latter is frequently determined by the tenderness of the meat (Udomkun *et al*., 2018). The tenderness of meat is most commonly determined through the objective measurement by means of the Warner-Bratzler shear force (WBSF) and is known to be influenced by numerous factors such as species, age, sex, collagen content, sarcomere length and rate of proteolysis of the important structural proteins (Kerry & Ledward, 2009). These factors also influence the pH_u and subsequently the meat tenderness as the pH_u and rate of pH decline influence the proteolytic enzymes responsible for the meat tenderness (Honikel, 2004; Kerry & Ledward, 2009; Troy & Kerry, 2010). Hoffman *et al.* (2007) reported a significant positive correlation between ultimate pH and shear force for Karoo springbok from different regions. Thus, the higher the $pH_{u,}$ the higher the shear force and consequently the tenderness decreases. Purchas, (1990) reported that between the pH_u values of 5.5 – 6.2 the shear force increased, and tenderness decreased. This was thought to be due to the decrease in the sarcomere length between the pH_u of 5.5 and 6.2. It is thought that this decrease in tenderness is due to the increase in pH_u of between 5.8 and 6.3, due to a speculated decrease in the proteolytic activity of the tenderising enzymes in this pH_u range (Yu & Lee, 1986). Although it was also reported by Devine *et al.*(1993) that the most tender meat in lambs occurred at a pH of 6.3.

Karoo springbok has a reported tenderness of between 15.8 and 30.3 N (Buys, Nortjé, & Van Rensburg, 1997; Hoffman *et al*., 2007a; North, Frylinck, & Hoffman, 2015; North & Hoffman, 2015). Region and species are known to influence the tenderness of meat, Karoo springbok (Hoffman *et al*., 2007a) had lower shear force values than Namibian springbok (Hoffman, van Schalkwyk, & McMillin, 2019), whilst blue wildebeest (Van Heerden & Hoffman, 2018), kudu (Hoffman, Mostert, Kidd, & Laubscher, 2009), red deer (Kudrnáčová, Bartoň, Bureš, & Hoffman, 2018; Postolache, Boişteanu, & Lazăr, 2011) and fallow deer (Kudrnáčová *et al*., 2018) all had different WBSF. This illustrates that species differ in terms of tenderness of their meat.

Male roe deer and impala had a higher shear force than female roe deer and impala (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012; Hoffman, 2000, respectively). Differences between sexes for tenderness can be partly attributed to Intramuscular fat (IMF) and collagen contents. Female mammals accumulate a higher percentage of fat than their male counterparts. This is thought to be a survival mechanism so that female mammals can maintain body condition to some extent during lactation (Young, 1976). Daszkiewicz et al.(2012), reported that female roe deer with a higher IMF content had a lower shear force compared to male roe deer with a lower IMF content. Collagen content and collagen solubility greatly influence the tenderness of meat (Lepetit, 2007; Lepetit, 2008), and the synthesis of collagen as well as the rate of collagen maturity is strongly influenced by testosterone (Gerrard *et al*., 1987). Thus, males have been reported to have a higher collagen content and consequently tougher meat. Although this would seem to be somewhat species specific. Hoffman *et al*. (2007a) reported that nether sex nor age influenced the shear force values of Karoo springbok meat. North *et al.* (2015) and North *et al.* (2016) also reported no differences between male and female Karoo springbok for shear force values. In Namibian springbok, male and female springbok also did not differ in terms of tenderness (Hoffman *et al*, 2019).

Table 2.1: Means of the physical meat quality characteristic of various game and domestic species

Species	Shear force (N)	Cooking loss	Drip loss	pH	Source
Karoo Springbok	15.8 – 17.9	28.7 – 31.5	2.7 – 2.8	5.63 – 5.73	Hoffman, Kroucamp, & Manley (2007a)
	20.15 – 23.3	22.6 – 26.8	-	5.49 – 5.50	North & Hoffman (2015)
	30.1 – 30.3	28.2 – 28.8	-	5.6 – 5.7	North *et al*. (2015)
Kalahari springbok	25.6 - 48.7	35.0 – 46.1	1.3 – 1.9	5.5 – 5.7	Hoffman *et al*. (2019)
Limosin	45.8	27.0	9.57	6.2	Xie, Meng, Cui, & Ren, (2012)
Simmentaler	52.6	29.4	10.3	5.6	
Palmera	37.2	22.6	-	-	Moreno-Indias *et al*. (2011)
Impala	31.9	31.0	1.2	5.57	Hoffman, Mostert, Kidd, & Laubscher, (2009)
	24.7 – 31.5	23.5 – 24.5	2.45 – 2.66	5.72 – 5.82	Hoffman, (2000)
Kudu	32.1	31.5	1.4	5.63	Hoffman *et al*. (2009)
Blue wildebeest	24.4 – 43.6	34.6 – 40.6	1.0 – 1.9	5.6 – 5.8	Van Heerden & Hoffman, (2018)
Red deer	18.4 – 37.1	26.25 – 34.3	2.9 – 3.2	5.54 – 5.66	Postolache, Boişteanu, & Lazăr, (2011)
	18.4 – 53.7	26.3 – 29.9	3.0 – 5.1	5.4 – 5.6	Kudrnáčová, Bartoň, Bureš, & Hoffman, (2018)
Fallow deer	19.7 – 47.8	26.4 – 33.5	1.1 – 2.8	5.52 – 5.68	
	47.8	-	-	-	Bureš, Bartoň, Kotrba, & Hakl, (2015)

Colour is a fundamental meat quality characteristic at point of purchase (Udomkun *et al*., 2018), as consumers use colour as a measure of freshness. Consumers discriminate against meat that is either too light or too dark (Issanchou, 1996). Colour is influenced by a variety of factors such as diet, pH_u, myoglobin content, muscle fibre type, species, breed and sex (Neethling *et al*., 2017). pH_u significantly influences the colour of game meat (Hoffman *et al*., 2007a, 2009) indicating that hunting practices and stress associated therewith will influence the meat's colour due to the influence of the *ante mortem* stress on the pH_u. A wounded and highly stressed impala was reported to have colour measurements (L* = 25.44, a* = 9.13, b* = 4.88; Hoffman, 2000) at a pH_u > 6.0. Acceptable game meat characteristically has colour measurements of L*< 33, low b* (±10), and high a* (>13) values (Shange, Gouws, & Hoffman, 2019; Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003)

The colour measurements of different species and different breeds have been determined (Table 2.2). Colour measurements between species can differ due to differences in myoglobin content and the proportion of muscle fibre types (Vestergaard, Oksbjerg, & Henckel, 2000). Myoglobin is the haem pigment that influences colour of meat (Stevenson, 1990). Game meat is commonly darker than domestic species' meat and this has been postulated to be due to the difference in amount of daily activity between game species (higher activity) and domestic species (lower activity) (Hoffman, 2000; Vestergaard *et al*., 2000). These activity differences cause variation in the myoglobin content of game species in comparison to domestic species and thus perceived colour (Neethling *et al*., 2017). Both Karoo and Kalahari springbok had lower L* and a* values than beef cattle (Table 2.2). Thus, Karoo springbok and Kalahari springbok meat is darker and less red than beef.

Sex influences the colour of game meat (Neethling *et al*., 2017), with male species generally having darker meat in comparison to their female counterparts. Hoffman *et al* (2007) reported that male and female Karoo springbok did not differ in terms of L* values. Whereas Hoffman *et al* (2019) in a later study reported that female springbok had a lower L* value and thus had darker meat than male springbok. In impala, males had a lower L* value and thus a darker meat in comparison to females; this was attributed to the level of activity in the males in comparison to females as males had just finished their rut season and were more active (Hoffman, 2000). Neither Hoffman *et al* (2007) nor Hoffman *et al* (2019) reported whether animals were in their breeding season or not, also this can be difficult to determine as springbok are non-seasonal breeders (Bothma & Du Toit, 2010). The lack of difference or abnormal pattern of L* sex-related differences could have been due to the Springbok in both studies not yet being in their breeding season. Hoffman *et al* (2019) also attributed the higher L* value of the males to the higher ultimate temperature of the male springbok's meat in comparison to the female springbok.

Differences in diets can cause differences in meat colour through differences in constituents (Lawrie & Ledward, 2006). However, dietary differences throughout the lives of animals can also influence growth rates and body compositions and so influence colour (Muir, Deaker, & Bown, 1998). Studies focusing on dietary differences have focused on the effect that roughage versus concentrate have on the colour of meat (Muir *et al*., 1998; Priolo, Micol, & Agabriel, 2001), although these studies have been limited to domestic species and very little research on dietary and feeding system effects on game meat has been studied (Neethling *et al*., 2017). Springbok are highly selective feeders and prefer a very wide range of plant species (Bigalke, 1972). However, their daily diet can differ between the different regions within South Africa and Namibia where this species occurs. Although diet it is considered a minor influencer of meat colour and can be overshadowed by *ante mortem* stress that influences the pH_u and subsequently the meat colour (Kerry & Ledward, 2009). This is illustrated in one of the few studies on different regions' effect of game meat colour, where the presence of an inexperienced culling team and subsequent high pH_u values overshadowed the effect that different regions had on springbok meat colour (Hoffman *et al*., 2007a).

Table 2.2: Means of the colour measurements of various species per sex, across various treatments

Species	Age	Sex	N	Treatment	L*	a*	b*	Ref
Beef Cattle	22 – 26 months	Male	575	Season	34.8	22.4	8.4	
		Female	640		36.5	22.6	8.7	#1
Karoo springbok	12 months – 5 years	Male	76	Sex, age and region	31.8	13.3	8.1	
		Female	90		32.2	14.9	8.5	#2
Kalahari springbok	12 – 24 months	Male	11	Sex, age and muscle	32.3	13.3	8.2	
		Female	8		31.2	12.8	8.03	#3
Impala		Male	8	Culling method	28.8	11.1	7.1	
		Female	8		29.7	11.4	7.6	#4
Fallow deer		Male	11	Sex	30.0	16.4	11.1	
		Female	10		29.9	12.2	8.13	#5

[#1] Kim, Yoon, Song, & Lee, 2003; [#2] Hoffman *et al*. 2007a; [#3] Hoffman *et al*. 2019; [#4] Hoffman, 2000; [#5] Piaskowska *et al*, 2015

2.5 FACTORS AFFECTING CARCASS AND MEAT YIELD

2.5.1 Species, age and sex

Yield refers to the percentage usable/ sellable carcass that can be obtained. It is usually the cold carcass or warm carcass weight expressed as a percentage of the dead weight (Warris, 2000). When yield is calculated from warm carcass weight, the yield is about 1.5-2.0% higher than yield calculated from cold carcass weight (Warris, 2000). Carcass weights are considered a good indicator of meat production potential (Von la Chevallerie, 1970). Comparison of yield across studies and species can be challenging as game species are culled in their natural environment at different times of the day or night. Combined with the fact that different game species have different feeding behaviours (Roosendaal, 1973). This means that *ante mortem* feeding is not as easily controlled before culling as it is in domestic species slaughtered in an abattoir. As gut fill affects the dead weight and so yield (Warris, 2000), the degree of *ante mortem* feeding can be a confounding factor in the determination of yield and in the comparison of yield between game species (Hoffman *et al*., 2009). This is illustrated by the difference in yield found between impala and kudu, where impala had a higher dressing percentage than kudu; these differences were attributed to differences in *ante mortem* feeding rather than intrinsic species differences (Hoffman *et al*., 2009).

The sex of an animal can influence its growth rate, and carcass characteristics (Lawrie & Ledward, 2006; Baron 2011). Male springbok have been reported to have a heavier dead weight and cold carcass weight than female springbok (Kroucamp, 2004). The dead weight and carcass weight of springbok at different ages has been determined (Hoffman, van Schalkwyk, & McMillin, 2019; Jooste, Conroy, & Fairall, 1990; Kroucamp, 2004; Van Zyl & Ferreira, 2004; Von la Chevallerie & Van Zyl, 1971). However, studies on springbok, commonly divide springbok into adult and sub-adult age categories. The onset of adulthood would seem to range between 12 months (Hoffman *et al*., 2019) and 17 months (Van Zyl & Ferreira, 2004) and 24 months (Kroucamp, 2004).

No differences for live- and cold carcass weights between male and female Namibian (Kalahari) springbok for the sub-adult or adult groups were noted (Hoffman *et al*., 2019). Although the weight differences between males and female springbok was 6kg, which was a similar to the difference reported by Kroucamp (2004), there was large variation in these weights. The Kalahari springbok were also the youngest adult classification, adult springbok was classed as being older between 12 – 24 months (Hoffman *et al*., 2019). Whereas Kroucamp (2004) classified adult springbok as 2 years and older whilst the sub-adult springbok were classed as 12 -24 months. There was no difference in live weights and cold carcass weights of the sub-adult group in Kroucamp's (2004) study. Age influences the dead weight as female springbok reach sexual maturity at 6 months but only start to mate at 10 – 12 months. In contrast male springbok only reach sexual maturity at 24 months (Furstenburg, 2016). Thus, female springbok attain 83 % of their mature weight at seven months, whereas male spring have only attained 57% of their body weight at seven months (Bothma & Du Toit, 2010). Thus, age influences the differences observed across studies for sex-related effects. Only springbok of comparable ages, will have similar sexual dimorphism patterns. Nonetheless, the data could indicate a tendency towards a difference in live weight and cold carcass weights and warrants more research, particularly where a more accurate age can be determined.

In the two remaining studies in which adult springbok were older than two years, the dead weight and carcass weights differences observed between male and female springbok were across a multitude of regions and in different seasons (Kroucamp, 2004; Von la Chevallerie & Van Zyl, 1971). The prevalence of a higher dead weight for males in comparison to females over the multitude of study regions could mean that sexual dimorphism will prevail when springbok are mature, independent of environment and season.

The body proportion of mammals varies across species, breeds, sexes, environments, ages and maturity types. In most studies on small ruminants, body proportions were determined by dividing carcasses into the five main primal cuts, namely: the neck, shoulder, front shank, ventral trunk, dorsal trunk, back leg and back shank (Figure 2.3).

1. Neck
2. Shoulder
3. Dorsal trunk
4. Ventral trunk
5. Back leg
6. Front shank
7. Back shank

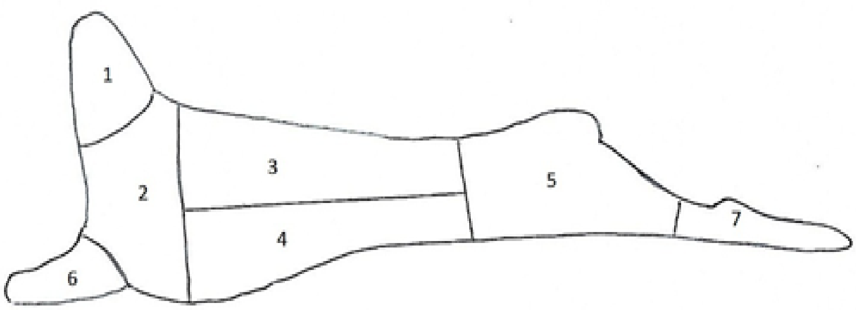

Figure 2.3: Illustration of the primal portion anatomical location

Various studies on different game/venison species have been conducted to determine the difference in proportional composition (Table 2.3). Proportional composition is economically important and can be utilised for increased meat production. There is still relatively limited research on the proportional composition of South African game species (Hoffman, 2000).

The proportional composition of an animal changes as it ages (Volpelli, Valusso, & Piasentier, 2002; Żochowska-Kujawska, Kotowicz, Sobczak, Lachowicz, & Wójcik, 2019). In fallow deer and red deer stags the neck percentage increased with age, whereas the shoulder percentage decreased with age (Drew & Hogg, 1986). Żochowska-Kujawska *et al.* (2019) reported an increase in the thorax with age of male fallow deer stags. Some proportional changes would seem to be species specific as it was reported for fallow deer and red deer that rib percentage decreased with age, whereas New Zealand wapiti had an increase in rib percent (Drew & Hogg, 1986). The proportional differences not only change with age but change differently depending on the sex on the animal. Males tend to have a heavier/ larger neck than female ruminants. The neck's growth rate has been reported to be higher in male springbok (Von la Chevallerie & Van Zyll, 1971), thus giving males a larger/ heavier neck than females at comparable ages. This is thought to be due to the neck being a dominant male trait (Dahlan, 2009) as is apparent in impala (Hoffman, 2000) and indigenous goats (Simela, Webb, & Bosman, 2011)

As males age, their forequarter becomes proportionally larger than their hind quarter, whereas in females the inverse occurs (Dahlan, 2009; Hoffman, 2000). When impala were divided into South African primal portions (Figure 2.3). The male impala had a higher percentage proportion breast, shank and flank (forequarter), whereas female impala had a higher percentage hind leg in comparison to male impala (Hoffman, 2000). Female indigenous goats also had a higher percentage hind leg in comparison to male indigenous goats (Simela, *et al*., 2011).

Age also influences the tissue composition of carcasses, as a younger animal will have a higher proportion of bone and a smaller percentage of muscle and fat in comparison to an older animal (Lawrie & Ledward, 2006). This is due to the progression of growth in which bone grows first, followed by muscle and fat is deposited last (Berg, 1968a, 1968b; Butterfield & Berg, 1966; Lawrie & Ledward, 2006). Von la Chevallerie & Van Zyl, (1971) reported the steady decrease of bone percentage and increase of meat percentage in springbok across ages, where bone: meat percentages starts at 33: 67 in one-week old lambs and ended in 15: 83 percent in sixty week old springbok.

Sex also influences the tissue composition of a carcass. Female animals have been reported to have a higher percentage fat in comparison to males (Renecker, & Mallory, 2005). Female mammals accumulate fat to aid in times of increased stress, such as lactation (Young, 1976). This increased fat subsequently causes that females have a slightly lower percentage of meat in comparison to males. Females also mature at an earlier age than males. Due to the progression of tissue deposition. As fat accumulates the percentage of bone and muscle decreases (Berg, 1968a, 1968b; Butterfield & Berg, 1966). Early maturing females grow at a faster rate than late maturing males early in life. This means that at similar ages, females will have a higher fat and lower bone and muscle percentage than males. Female springbok reaches 83 % of their mature body weight in 7 months, whereas males only reach 57% of their mature body weight at the same age (Bothma & Du Toit, 2010). Thus, female springbok would start to accumulate fat at a younger age than male springbok. Von la Chevallerie & Van Zyl, (1971) reported that adult female springbok had a higher fat content and lower meat content in comparison to male springbok when the hind leg was dissected. Female indigenous goats also had a higher fat and lower meat percentage in comparison to their male counterparts (Simela *et al*., 2011).

Table 2.3: The proportional (%) carcass composition of various game species reported as a percentage of the cold carcass weight

Species	Sex	Age	Neck	Forelimb	Ventral trunk	Dorsal trunk	Back leg	Source
Rusa deer				52.7 – 54.6		45.4 – 47.3		Dahlan (2009)
Springbok (Kalahari)	Male	Adult	-	-	-	16.5 – 17.3	35.8 – 36.1	van Schalkwyk, (2019)
Impala	Male		5.1 – 6.9	35.5 – 36.8	8.1 – 8.4	7.4 – 7.9	43.0 – 40.5	Hoffman (2000)
	Female							
Fallow deer			5.6 – 6.7	-	-	-	-	Fitzhenry *et al* (2019)
	Male	1 year	11.3	17.7	13.9	17.6	39.5	
		2 year	12.5	17.0	11.6	17.4	40.5	
Red deer	Male	1 year	10.6	19.7	15.5	15.5	39.4	Drew & Hogg, (1986)
		2 year	16.1	18.8	11.4	14.4	38.2	
		9 year	23.7	20.3	8.1	18.6	33.1	
Elk	Male	2 years	13.2	16.1	11.3	16.6	39.9	
		4 & 5 years	18.6	19.5	13.6	13.1	39.9	

2.5.2 Intensity of culling

Culling refers to the selective killing of animals, whereas harvesting refers to no selection criteria for culling and/or the number of animals harvested, independent of size, sex or even age. Trophy Hunting is an example of a selective culling action.

Springbok are an extremely popular species for trophy and biltong hunting. They are the second most popular species for trophy hunting and the most popular species for biltong hunting. Approximately 27 % of the animals culled in a year by biltong hunters are springbok (Taylor *et al*., 2016). For a springbok ram to be considered a Rowland trophy its horn size is thought to be reached after approximately 5 years (Furstenburg, 2016). Springbok are thought to increase in live weight until approximately the age of 6 years (Furstenburg, 2016), although the genetic relationship between horn size and mature body size has not been determined. This implies that rams culled for trophies or trophy hunting are mature older rams (Bothma & Du Toit, 2010) and these rams are frequently the breeding rams (Skinner & Louw, 1996).

When there is a high intensity of culling, the number of mature males in the population/herd decreases (Coltman *et al*., 2003; Festa-Bianchet, Pelletier, Jorgenson, Feder, & Hubbs, 2014). In the wild, rams under the age of four years old would not easily acquire a territory (Skinner & Louw, 1996). High intensity of selective culling for larger animals allows for younger males to occupy territories that they otherwise would not have, and these younger males will thus have a greater chance to sire progeny. In a population that is less selectively hunted these younger males would have formed part of the bachelor herds and would most likely have been culled/harvested. This would mean that the younger males would have had less opportunity to sire progeny (Skinner & Louw, 1996). Faster growing rams, reach a desirable live weight at an earlier stage and are thus culled before they can sire sufficient progeny (Festa-Bianchet *et al*., 2014).This phenomenon is common in rural goat herds where goats are culled as soon as they reach a desirable live weight. This means that the slower growing rams breed to a larger extent than the faster growing rams and causes the population/herd growth rate to decrease (Simela, Ndlovu, & Sibanda, 1999). Similarly, selective culling in big horned sheep has led to a decreased number of annual trophy numbers (Festa-Bianchet *et al*., 2014). Big horned sheep (*Ovis canadensis*), are popular for trophy hunting; this selection pressure has caused a notable decline in body size and horn size of big horned sheep in a population that has experienced selective culling (Coltman *et al*., 2003; Festa-Bianchet *et al*., 2014).

Although hunting, whether for biltong or trophy, is economically important to both the game rancher and the South African economy, the effect of selective culling is an important factor that should be considered in the management practices of game ranchers.

2.6 INTRINSIC FACTORS AFFECTING CHEMICAL COMPOSITION OF MEAT

Game meat has a natural advantage in that it is classified as organic due to the free range and antibiotic free nature in which animals are produced (Hoffman, 2000). Consumers have become more health conscious in the last decade and most consumers prefer meat that has a low level of fat and is thus seen as healthier. Game species' meat is naturally very low in fat with game meat rarely exceeding 3% intramuscular fat (Hoffman & Wiklund, 2006). This implies that game species' meat can be a unique solution for health conscious consumers

The chemical composition of lean meat is determined through the proximate components, moisture, fat, protein and ash. The proximate components then in turn determine the nutritional value of meat. Various studies have determined the proximate composition of different species and different breeds (Table 2.4) The proximate composition of Karoo springbok has been determined to be 72.7 – 73.5% moisture, 18.8 – 21.2% protein, 1.3 – 8.0% fat and 1.3 – 3.5% ash (Hoffman, Kroucamp, & Manley, 2007b). On the other hand, the proximate composition of Namibian springbok meat has been reported as: 72.1 – 74.7% moisture, 19.4 – 22.8% protein, 2.4 – 3.5% fat and 1.1 – 1.2% ash (Hoffman, van Schalkwyk, & McMillin, 2019). The study by Van Zyl & Ferreira, (2004), reported higher fat percentage for Karoo female springbok than the values reported by Hoffman *et al*. (2007b), this discrepancy between studies could have been due to the small sample size of the Karoo female springbok (n=3) in the study by Van Zyl & Ferreira, (2004). Also, Van Zyl & Ferreira analysed the proximate of the whole carcass, including visceral fat and organs; this could have resulted in higher fat levels being analysed compared to that typically found in springbok meat. Excluding Van Zyl & Ferreira's, (2004) values, then the springbok subspecies seemed to have similar proximate compositions. Both Karoo and Namibian springbok have lower IMF values than various sheep breeds such as Dorper and Damara and goat breeds such as boer goats and indigenous goats (Tshabalala, Strydom, Webb, & De Kock, 2003), but have similar IMF content to SAMM and dormer sheep breeds (Cloete, Hoffman, Cloete, & Fourie, 2004). Impala, black wildebeest and red deer all had similar IMF content to springbok (Hoffman, Schalkwyk, & Muller, 2009; Hoffman, 2000; Van Zyl & Ferreira, 2004).

Sex differences in the proximate composition of various species such as springbok, impala, roe deer and kudu has been reported. These differences are frequently due to differences in the IMF content between sexes (Daszkiewicz *et al*., 2012; Hoffman *et al*., 2007b, 2009). Female mammals tend to have a higher degree of fat deposition as a survival mechanism in comparison to males (Young, 1976). The IMF and moisture and protein content of springbok have been reported to be negatively correlated (Hoffman *et al*., 2007b). These relationships between proximate components implies that female animals with a higher IMF will subsequently have a lower protein or moisture content in comparison to males. Frequently the IMF content between sexes do not differ for game species, such as reported in hartebeest (Hoffman, Smit, & Muller, 2010), kudu (Mostert & Hoffman, 2007) and mountain reedbuck (Hoffman *et al*., 2008). The extent of these differences between males and females can be somewhat situation dependant. Males during the rut loose mass, of which the largest portion is fat (Barboza, Hartbauer, Hauer, & Blake, 2004). Thus, males during a rut have a lower IMF content than those before the rut season. Thus, studies that culled males in the rut season were more likely to have a very significant differences in IMF content and subsequently protein and moisture differences between males and females.

Age can also influence the chemical composition of meat. Young animals are still in a phase of bone and muscle growth, only when an animal becomes older does it start to accumulate fat (Lawrie & Ledward, 2006). Thus, older animals have a higher IMF content and subsequently a lower protein and moisture content. This is illustrated in springbok from different regions, where lambs had a lower IMF content than adult springbok and thus a higher moisture content (Hoffman *et al*., 2007b). In contrast both Karoo and Namibian springbok had similar proximate compositions between sub-adult and adult groups (Hoffman *et al*., 2007b; Hoffman *et al*., 2019).

Table 2.4: The chemical composition (%) of various species

Species	Protein	Moisture	IMF	Reference
Springbok (Karoo)	18.8 – 21.2	72.7 – 73.5	1.3 – 3.5	Hoffman *et al*. (2007b)
	30.4 – 31.1	64.8 – 66.2	2.5 – 3.2	North & Hoffman, (2015)
	22.9 – 24.2	60.8 – 63.1	3.5 – 8.0	Van Zyl & Ferreira, (2004)
Springbok (Kalahari)	19.4 – 22.8	72.1 – 74.7	2.4 – 3.5	Hoffman *et al*. (2019)
Impala	22.1 – 22.6	59.7 – 65.0	1.3 – 5.8	Van Zyl & Ferreira, (2004)
	23.5 – 24.0	71.9 – 72.8	2.5 – 3.4	Hoffman, (2000)
Black wildebeest	20.5 – 24.3	74.3 – 75.9	0.9 – 1.22	Hoffman, Schalkwyk, & Muller, (2009)
Red deer	21.4 – 21.8	73.7 – 74.9	2.4 – 3.2	Postolache *et al*. (2011)
Goats	22.8 – 24.8	69.4 – 69.8	7.9 – 10.5	Tshabalala, Strydom, Webb, & De Kock, (2003)
Sheep	21.4 – 22.5	60.2 – 61.7	19.4 – 20.4	Tshabalala, Strydom, Webb, & De Kock, (2003)
SAMM	22.2	74.1	3.33	Cloete, Hoffman, Cloete, & Fourie, (2004)
Dormer	21.9	74.3	3.0	

2.7 THE SPRINGBOK

2.7.1 Subspecies

Springbok are the most abundant antelope species present in South Africa with numbers of up to two million in South Africa and 750 000 in Namibia. Originally there were three sub-species recognised by Zimmerman (1780). The Karoo springbok (*Antidorcas marsupialis marsupialis*), which commonly occurs in South Africa. The Kalahari springbok (*Antidorcas marsupialis hofmeyri*) which commonly occurs in the southern parts of Namibia and lastly, the Damara springbok (*Antidorcas marsupialis angolensis*). The Damara subspecies occurs in the northern parts of Namibia and in Angola (Skinner, 2005). There was some controversy on the accuracy of recognising the subspecies as some ecologists thought that the three subspecies were merely ecotype and not true subspecies (Bothma & Du Toit, 2010). Zimmerman (1780) firstly identified the three subspecies but later Robinson (1975) reported that the recognition of subspecies was unnecessary. Robinson's (1975) classification was commonly adopted (Skinner & Louw, 1996), until skulls were found that suggested differences in the size of springbok subspecies (Furstenburg, 2016). Recently *A. m. angolensis* has been referred to as Damara springbok and for the purposes of this study, will continue to be referred to as such. There seemed to be a notable size difference between the three subspecies with the Damara being the largest and the Karoo the smallest. This size difference was thought to be only due to differences in quality and quantity of nutrition (Robinson, 1975; Furstenburg, 2016) or even differences in protein of vegetation in different regions (Robinson, 1979). Later it was suggested that the differences in frame size could rather be attributed to a difference in the allele length of the tandem BMP4 repeat (Van Aswegen, Labuschagne, & Grobler, 2012). Van Aswegen *et al*. (2012) only investigated the difference between Karoo and Kalahari springbok, the validity of the recognition *A. m. Angolensis* as a separate subspecies has been questioned, but has yet to be researched (Furstenburg, 2016).

2.7.2 Adaptability and herd structure

Springbok are highly adapted to a variety of environments. Springbok can survive in harsh environments and this is attributed to the way in which they utilise the environment for water and energy (Nagy & Knight, 1994). Springbok are water independent as opposed to Impala that are water dependent (Bothma & Du Toit, 2010). This does not mean that springbok can go a lifetime without water but rather that they have highly adaptive measures in which they obtain water. They selectively graze plants with higher moisture contents and adapt their feeding behaviour. Initially it was suggested that springbok, similar to camels, can survive virtually without water (Bigalke, 1972). Even though springbok can survive on small amounts of water, if there is water present in their immediate environment, they will drink often. It has been suggested that rather than surviving without water that they are very specific feeders, preferring to feed early in the mornings and late at night when moisture content of plants are higher. It has also been suggested that in the dry season springbok will mostly feed on shrubs and in the wet season they prefer grasses, when grass is available (Nagy & Knight, 1994). In the season in which food is plentiful due to rainfall, springbok have water economy indices resembling that of non-desert animals while in the dry season the have water indices similar to desert animals, showcasing the fact that springbok have water conserving mechanisms that they can make use of in the dry season but that they also tend to only make use of these mechanisms such as concentrated urine when necessary (Hofmeyr & Louw, 1987). Springbok use these methods to maintain their water balance and this allows them to adapt to harsh environments (Nagy & Knight, 1994). Springbok can also sense water from vast distances and migrate continuously after water (Bigalke, 1972; Bothma & Du Toit, 2010).

Springbok are mixed feeders and both graze and browse (Bothma & Du Toit, 2010). They are commonly short grass grazers and thus frequently occur in the open and short grasslands of the Karoo and Kalahari (Bothma & Du Toit, 2010).

Springbok do not need a 1:1 male-to-female ratio for successful mating. Ideally a springbok herd should have at least one male for every thirty females (Skinner & Louw, 1996) and the breeding males are very territorial and solitary. Males that are not dominant enough to occupy their own territory will be less likely to breed. Therefore, males younger than three or four years old rarely occupy territories (Skinner & Louw, 1996). These younger surplus males generally form bachelor herds and are ideal for culling for meat production (Skinner & Louw, 1996) consequently springbok are extremely promising in terms of their potential for meat production (Bothma & Du Toit, 2010).

2.7.3 Age

The method of age determination of springbok was originally reported by Rautenbach (1971). Mature springbok age is determined by wear and tear and horn size, as illustrated in Figure 2.4 and Figure 2.5, these methods are commonly used in most research that has been conducted on springbok (Hoffman *et al*., 2007a, 2007b; Hoffman *et al*., 2019; North *et a*l., 2015; North, Frylinck, & Hoffman, 2016). Age is important to determine as age has been reported to influence yield, meat quality and meat chemical composition (Hoffman *et al.,* 2007a; Hoffman, Kroucamp, & Manley, 2007c). However, as seen in these two diagrams, there is still huge variation between the age predictions. With the growth in the ranched wildlife sector, animal production principles are being applied. One important principle being applied is the individual numbering and record keeping which will ensure more accurate age determination and will help researchers quantify age effects. On the downside, very few springbok stud breeders are tagging their animals as the stud value of a springbok is still deemed to be too low to warrant the expenses.

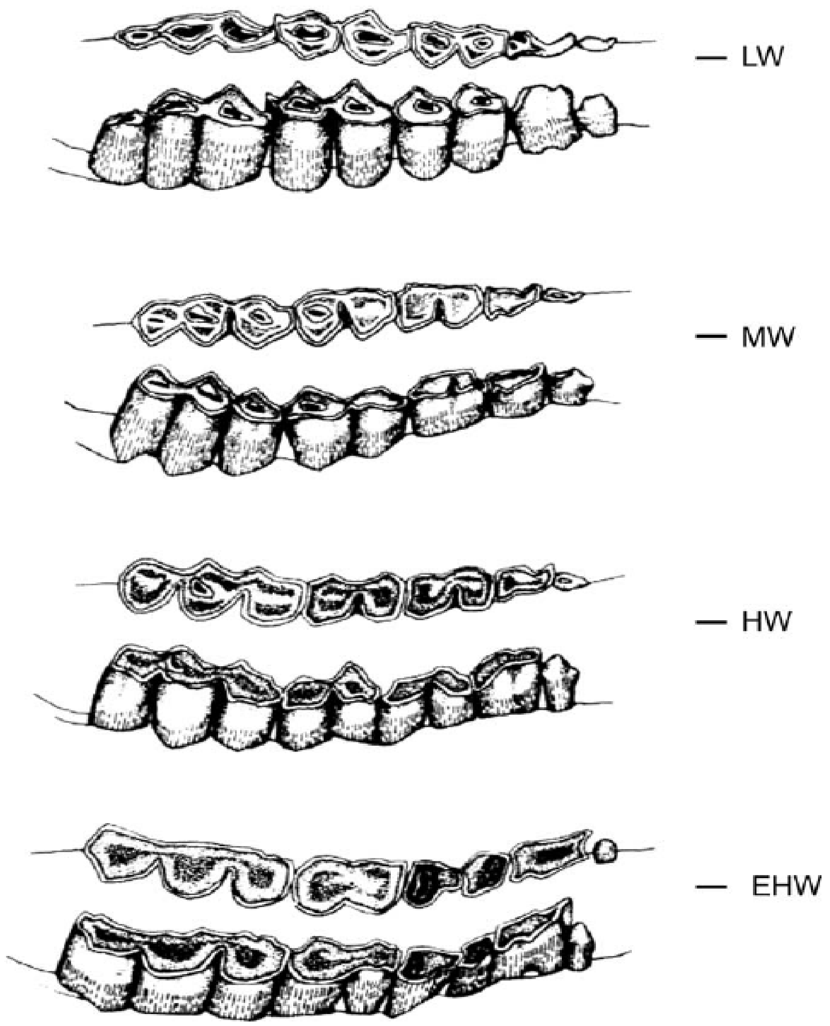

Figure 2.4: Mandibular dentition of springbok, showcasing wear and tear stages. LW = light wear (2 – 3.5 years), MW = moderate wear (3.5 – 5.5 years), HW = heavy wear (5.5 – 7.5 years) and EHW = extra heavy wear (> 7.5 years) as described by Rautenbach, (1971).

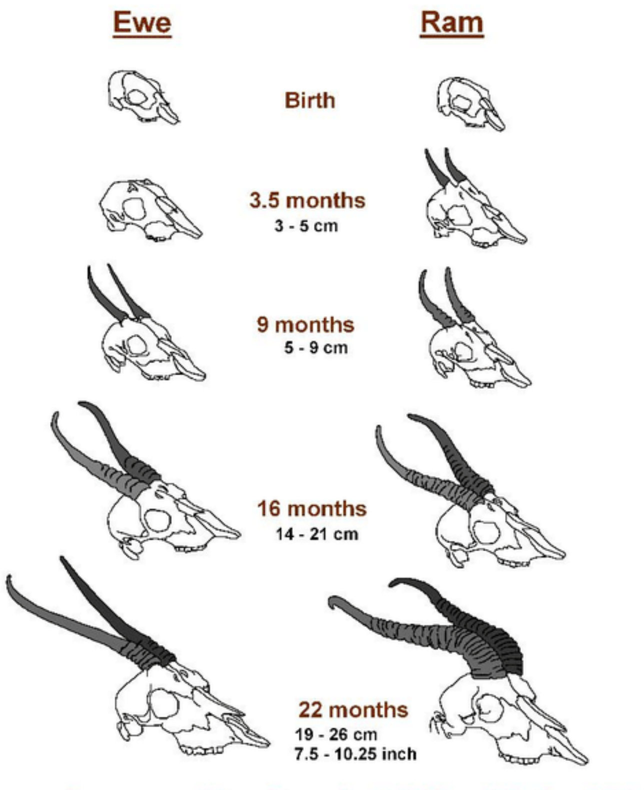

Figure 2.5: Horn growth of springbok rams and ewes Furstenberg (2016), as adapted from Rautenbach (1970) and Bothma (1986).

2.8 CONCLUSION

Springbok are a very abundant species and are well adapted to arid environments that most domestic species could not thrive in. Springbok also have a highly favourable carcass yield and are promising in terms of meat production and meat quality. This causes springbok to be a very popular game species for hunting and high-end meat production. Various studies have determined some factors that could affect springbok yield and springbok meat quality. It would be beneficial to further determine factors affecting the yield and meat quality in terms of subspecies, sex and intensity of culling. The Karoo and Kalahari springbok differ in terms of yield but there is no information available on the meat yield and meat quality of the Damara springbok (*Antidorcas marsupialis angolensis*). Breeders and producers have already started breeding the large Damara and Kalahari springbok onto the smaller Karoo ram with the idea of increasing the carcass yields of their animals. It is therefore crucial that more baseline data be collected that evaluates the impact of subspecies (Damara vs Karoo) and intensity of culling on the yield and fresh meat quality of this popular iconic species.

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CHAPTER 3

THE INFLUENCE OF SUBSPECIES, SEX AND INTENSITY OF CULLING ON THE CARCASS YIELD, OFFAL YIELD AND BODY MEASUREMENTS OF SPRINGBOK (*ANTIDORCAS MARSUPIALIS*)

ABSTRACT

This investigation determined the effect of subspecies (Damara vs Karoo), sex and intensity of culling on carcass parameters and body dimensions of springbok. A total of 60 springbok were culled from three different farms, two located in South Africa (*A. marsupialis marsupialis)* and one in Namibia (*A. m. angolensis*). Dead weight had significant sex effects and significant differences between Damara and Karoo subspecies. Cold carcass weights also had significant subspecies differences and sexual dimorphism for Damara and Karoo, where the Damara subspecies and males had heavier cold carcass weights. Male springbok had higher dressing percentage than females. Total offal yield had significant sexual dimorphism and a subspecies effect between Damara and Karoo springbok. There was a significant subspecies effect for all linear body measurements that were highly correlated to body weight. In the intensity of culling trial Wellington males (lightly culled) had significantly heavier dead and cold carcass weights than Wellington females. There were a significant intensity of culling and sex effects for dressing percentage for Wellington and Witsand springbok. There were no significant differences for total offal yield between the intensively culled Witsand and Wellington males. The Wellington males had significantly larger body dimensions than Witsand males for all the linear measurements; these were also highly correlated to body weight. The differences in body weight observed between Damara and Karoo subspecies have economic implications when animals are paid per carcass weight whilst the intensity of over-culling affects linear body measurements and yields of particularly male springbok compared to female springbok – a phenomenon typical of selective culling for larger trophy animals.

Keywords: Springbok, subspecies, carcass yield, offal yields, body dimensions

3.1 INTRODUCTION

Protein malnutrition in Africa continues to be a concern (De Onis, Monteiro, Akre, & Clugston, 1993) and has instigated the need for complementary protein sources to be considered (Wu *et al.*, 2014). Although some consumer-driven trends have caused a significant shift away from animal-derived protein (Florkowski, 2008), this has certain practical limitations within the southern Africa production potential context, such as South Africa's land composition allowing for only 17% of land to have the ability to produce crops. Eighty-three percent of agricultural land in South Africa is a natural veld that is used for grazing by cattle, sheep, goats and game species (NAMC, 2006) whilst in Namibia, as much as 84% is utilised for grazing (Namibia Statistics Agency, 2016). Game/venison animal-derived meat and offal offer a unique solution with regards to both production and health concerns that consumers associate with domestic animals' meat production; as game meat is lower in fat and higher in protein than domestic animals (Hoffman & Wiklund, 2006). Game ranching in South Africa has recently increased in popularity and there has been a steady increase in farms that either switch to game ranching or convert at least a portion of their land to game ranching (Cloete, Taljaard, & Grové, 2007; Taylor, Lindsey, & Davies, 2016). In 2014, approximately 17 041 900 ha was used for game farming (Taylor, Lindsey, & Davies-Mostert, 2016) and the allocation of land to game farming increased with approximately 5% every year (NAMC, 2006). Game ranching, if done correctly, can be beneficial to supporting biodiversity (Barnes & De Jager, 1996; Lindsey, Roulet, & Roman, 2006; Minin, Leader-williams, & Bradshaw, 2020) and has been noted to be a contributing factor to the increased improvement that has been observed in rangeland conditions (Meissner, Scholtz, Africa, & Palmer, 2013).

Springbok commonly occur in the more arid parts of southern Africa (Skinner & Chimimba, 2005), where crop production potential is very low. There is an estimated 1.5 million springbok in South Africa and 730 000 in Namibia (Furstenburg, 2016). Springbok is one of the most abundant species on privately owned game farms in South Africa, with the highest numbers in the Karoo (Jooste, 2011; Taylor, Lindsey, & Davies-Mostert, 2016). Springbok is the third most hunted species for trophies and the most popular species for biltong (Taylor, Lindsey, & Davies-Mostert, 2016). They are by far the most exported game meat (McCrindle, Siegmund-Schultze, Heeb, Zárate, & Ramrajh, 2013) and are seen as one of the most important game species (Jooste, 2011). The three subspecies of springbok namely Damara (*A. m. angolensis*), Kalahari (*A. m. hofmeyri*) and Karoo (*A. m. marsupialis*) differ dramatically in terms of live weight. This difference in weight has been attributed to differences in quality of forage (Furstenburg, 2016), but has also been suggested to rather be a genetic difference (Van Aswegen, Labuschagne, & Grobler, 2012). Very little research has been conducted to determine how the subspecies differ from one another, such as how they differ in carcass and offal weights and body measurements. Linear measurements are frequently used as predictors for live weight (Pesmen & Yardimci, 2008). These prediction equations are especially useful in cases where scales are not readily available, such as in the case of wild animals (McCulloch & Talbot, 2019), but can be very species-specific (Sachs, 1967) and not all linear measurements are equally correlated with live weight (Agamy, Abdel-Moneim, Abd-Alla, Abdel-Mageed, & Ashmawi, 2015).

Protein deficiency in human diets is a challenge that can be somewhat aided by the efficient use of game by-products, which are currently drastically underutilised. The game industry is continuing to grow but there is very little utilisation of offal being implemented in contrast to offal from domestic animals that form part of the income gained (McCrindle *et al*., 2013). Offal is an important protein source, especially in poorer parts of Africa and the utilisation of game offal could contribute to increasing food security to the most vulnerable parts of the South African population (Fayemi, Muchenje, Yetim, & Ahhmed, 2018; McCrindle *et al*., 2013; van Vliet, Nebesse, Gambalemoke, Akaibe, & Nasi, 2012). Effective utilisation of animal by-products is not only more economically efficient but also environmentally responsible (Ockerman & Hansen, 2000; Von la Chevallerie, 1970).

With the game industry's continued growth and expected future growth, proper management practices should be exploited and developed. One such practice is the extensive over-culling of a springbok herd typically found when hunters are allowed to cull any animal and pay per carcass shot rather than per body weight. The effect that the intensive culling has on the body measurements and carcass weights of a springbok herd has yet to be determined.

This research chapter aims to quantify the difference in dead weight, carcass weight, dressing %, offal yield and body dimensions between Damara and Karoo springbok for males and females (Trial 1) and to determine the difference between high and low intensity of culling for the dead weight, carcass weight, dressing %, offal yields and body dimensions of male and female Karoo springbok (Trial 2).

3.2 METHODS AND MATERIALS

3.2.1 Animals and study location

Sixty animals were culled over two months on three different farms. Twenty animals were culled (10 rams and 10 ewes) on each farm and only mature animals were selected. Age of animals was determined by wear and tear of teeth (Dewar, Halkett, Hart, Orton, & Sealy, 2006). Damara and Karoo (Wellington) springbok were between 18 months and five years old. Karoo springbok from Witsand ranged in age between 12 month and 2 years old.

Trial 1 (Subspecies comparison) consisted of 40 springbok: 20 Damara (*A. m. angolensis*) and 20 Karoo (*A. m. marsupialis*). The 20 Damara springbok were harvested in the dry month of July 2018 on Mount Etjo (Farm A), a farm in the North of Namibia, located in the Otjozondjupa Region of Namibia. The animals were in an enclosed area of 22 000 ha and received no supplementary feed. The most prominent veld type in this region is thornbush-savanna, with acacia trees and sweetveld mostly occurring on the farm. The 20 Karoo springbok were harvested in September 2018 on Elandsberg (Farm B) located near Wellington. The animals roamed freely in an enclosure of approximately 4 000 ha and received no supplementary feed. The farm is located within the fynbos biome with shale *Renosterveld* as the dominant veld type (Mucina, & Rutherford, 2006). The camp also consisted of a portion of abandoned (20 years ago) cultivated land that consisted predominantly of common couch grass (*Elymus repens)*. The springbok could move freely between the natural veld and the old cultivated field.

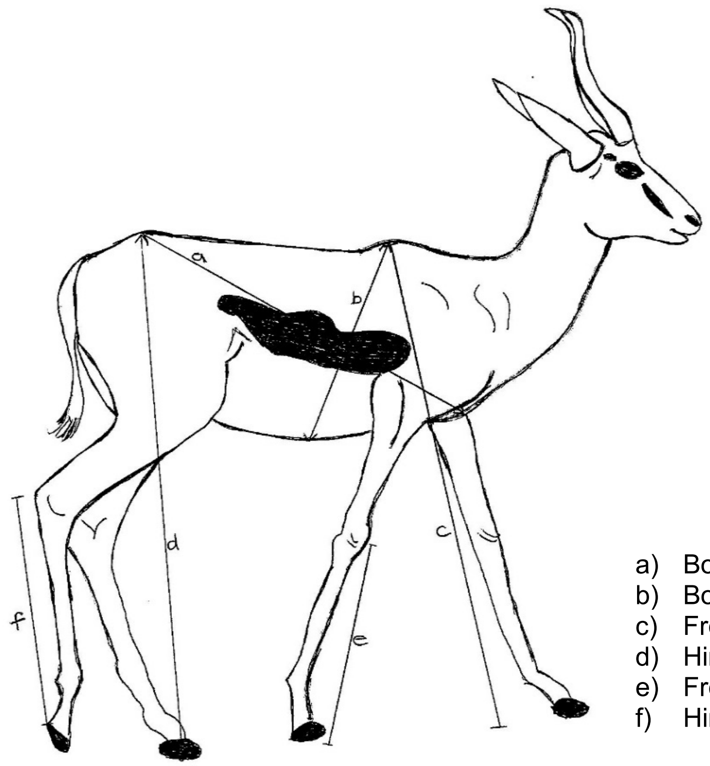
Trial 2 (intensity of culling comparison) was made up of the same 20 Karoo springbok from Wellington (Farm B) and 20 Karoo springbok from Witsand (Farm C). The Witsand's (Farm C) springbok were in a range of camps (through which they could freely move) that fell within the *fynbos* biome with the east coast *Renosterveld* being the dominant veld type (Mucina, & Rutherford, 2006). The farm near Witsand frequently culled Springbok with a focus on the larger, mature rams until there were almost no sexually matured males left on the farm. This farm serves as an example of over culling/overhunting.

3.2.2 Culling and Dressing

Animals were harvested in the same fashion on each of the three farms. Animals were randomly selected within sex and shot in the head with a .243 calibre rifle and were exsanguinated within two minutes of killing (Ethical Clearance Number: 10NP_HOF02). The animals were numbered in the field and records were made of the sex. Afterward, the animals were loaded onto the hunting vehicle and transported back to the designated slaughtering area within 2 hours *post mortem*. At the slaughtering area, the animals were unloaded, and the dead body weight recorded, and body measurements taken as described below in 3.2.3. Thereafter the head was removed between the *atlas* and the *axis* junction. The head and tongue weight was recorded and the age was determined according to Dewar *et al.* (2006). The skin and legs (*metacarpals* and *metatarsals*) were then removed, and animals were eviscerated in the prescribed method (van Schalkwyk & Hoffman, 2010) by an experienced team. Dressed warm carcass weight was then recorded before the carcasses were chilled at 4°C. Carcasses were removed from the chiller after 24 hours (day 2 *post mortem*) and weighed to determine cold carcass weight.

3.2.3 Body measurements

Different body measurements (Figure 3.1) were taken directly before the head, legs and skin were removed. All measurements were taken using a pliable measuring tape. These measurements included the hind leg length, that was measured from the tip of the pin bone (*iliac crest)* to the hoof and from the hind knee joint (*Tuber calcis*) to the hoof. The foreleg was measured from the tip of the shoulder bone (*Scapula)* to the hoof and from the front knee joint to the hoof. The slaughter process then continued as described in 3.2.2. Additional body measurements were then taken on the carcass 24 hours after slaughter and before deboning took place. The neck circumference was measured at the base of the neck as well as the pin bone (*iliac crest)* to pin bone (*iliac crest)* and shoulder (*scapula*) to shoulder (*scapula*) distance. The body depth measured from the tip of the shoulder (*scapula)* to the middle of the stomach was noted, as well as the body length measured from the tip of the pin bone (*iliac crest)* to the middle of the sternum.



a) Body length
b) Body depth
c) Front leg length
d) Hind leg length
e) Front knee to hoof length
f) Hind knee to hoof length

Figure 3.1: Illustration of linear body measurements positions.

3.2.4 Statistical analysis

Statistical analysis was done using the Statistica 64 version 13.4 (2018) VEPAC model. Trial 1 had a 2x2 factorial design experimental layout with subspecies (Damara and Karoo) and sex (male, female) as the two main effects with animal included as a random effect. A two-way ANOVA (univariate analysis of variance) was constructed using the General linear model

(GLM) of STATISTICA to test for significant differences between main effects (subspecies and sex) and for significant interaction of main effects (subspecies x sex). Age was also included as a covariate. Trial 2 was a 2x2 factorial design experimental layout with intensity of culling (Wellington n=20, Witsand n=20) and sex (male, female) as the main effects. A two-way ANOVA (univariate analysis of variance) was constructed using the General linear model (GLM) of STATISTICA to determine significant differences between main effects. Correlation was calculated between dead body weight and linear body measurements for Trial 1 and 2 and Pearson's correlation coefficients were used to determine significant correlations. Shapiro Wilk was used to test the underlying assumption of normality (Shapiro, Wilk, & Unwin, 2013). Levene's test was conducted to test for deviation from homoscedasticity. Significance level of 5% was used.

3.3 RESULTS

3.3.1 Subspecies comparison (Trial 1)

3.3.1.1 Carcass

The effect of subspecies (Damara vs Karoo) and sex on the offal weights are presented in Table 3.1. Dead weight and cold carcass weight had subspecies ($P<0.001$) and sex ($p<0.001$) differences. Male springbok had heavier dead weighs and cold carcass weight and higher dressing percentage than females. Furthermore, Damara males (43.37±0.869 kg) and females (36.59±0.923 kg), had a heavier dead weight than Karoo males (32.04±0.868 kg) and females (26.81±0.660 kg). Damara males had a heavier cold carcass weight than Damara females, Karoo males, and Karoo females. Damara females had a heavier cold carcass weight than Karoo females but did not differ significantly from Karoo males. Dressing percentage did not differ between subspecies.

The head weight differed across subspecies ($P<0.001$) and sex ($P<0.001$). The head (kg) differed significantly across all treatment combinations, with Damara males weighing the heaviest followed by Karoo males, Damara females, and Karoo females. Although there was no significant subspecies effect on the head proportion, but there was a sex effect ($P<0.001$), where males had the highest proportion head. There was a notable subspecies ($P<0.001$) and sex ($P<0.001$) effect for the skin weight, where the skin weight was heavier for the Damara males than all other groups although there was no significant difference between the Damara females and Karoo males. The Karoo females had the lightest skin weight. The leg weights differed significantly for all treatment combinations with Damara males having the heaviest legs, followed by Damara females, Karoo males, Karoo males, and Karoo females.

There was a significant difference for the heart weight between the Damara male and Damara female groups, but the Karoo males did not differ significantly from either the Damara male or Damara female group. The Karoo subspecies had a higher heart (P<0.001) percentage than the Damara subspecies. For the lungs, there was no significant difference between sexes within subspecies, but the Damara male and Damara female did differ significantly from the Karoo male and Karoo female. The Damara male had a significantly heavier liver weight than all other treatment combinations and there was no significant difference between Damara females and Karoo males for liver weight. The Karoo subspecies had a higher liver proportion (P<0.001). The GIT differed between subspecies (P<0.001). There was no significant difference in GIT between sexes for both Damara and Karoo; the Damara had significantly heavier GIT than the Karoo subspecies. There was a significant interaction between subspecies and sex for the kidney weights (P=0.021). The Damara male had a significantly heavier kidney weight than the other treatment groups, followed by the Damara female. There was no significant difference between Karoo males and Karoo females, but both differed significantly from both Damara males and Damara females. The Damara males had a significantly higher external offal weight (6.81±0.11 kg) than the Karoo males (4.45±0.35 kg) but there was no significant difference in the contribution of external offal to the dead weight between males of the two subspecies. Females, however, did differ significantly for external offal weight and contribution between subspecies. Total internal offal differed significantly between subspecies but the contribution of internal offal to the dead weight did not differ between Damara males and Karoo males and between Damara females and Karoo females.

The Damara males had a significantly heavier total offal weight (15.98±0.26 kg) than the Damara females (14.55±0.32 kg) and the Karoo males (10.63±0.58 kg) and Karoo females (9.13±0.35 kg). The Karoo males also had a significantly heavier offal weight than the Karoo females, thus there were significant subspecies and sex effects for the total offal weight.

3.3.1.2 Body dimensions and correlations

The effect of subspecies (Damara vs Karoo) and sex on the body measurements are presented in Table 3.2 and correlations between linear body measurements and deadweight in Table 3.5. Body length differed significantly between all subspecies x sex combinations, with Damara males (86.63±075 cm) having the longest bodies and Karoo females (72.44±0.998 cm) the shortest (Table 3.2). Subspecies (P<0.01) and sex (P<0.001) effects were found for the body depth and shoulder width. Damara males also had the deepest body depth and shoulder-width, whereas the Karoo females had the least body depth and narrowest shoulders. Both Damara females and Karoo males had intermediate body depths and shoulder widths. Neck circumference had subspecies (P<0.01) and sex (P<0.001) differences. Where Damara males had a significantly thicker neck circumference than Karoo males and Damara and Karoo females had smaller necks. The front leg length only differed between sexes (P=0.017) where between Karoo males and females but did differ significantly between Damara males and females. The hind leg length was significantly longer in the Damara subspecies when compared to the Karoo subspecies and sex differences were only observed in the Karoo subspecies for hind leg length. The Damara subspecies also had a significantly longer hind and front knee to hoof measurement but no significant difference between sexes was observed for both measurements. Body length (0.96, P<0.01), body depth (0.85, P<0.01), neck circumference (0.61, P<0.01), hind leg length (0.90, P<0.01), front knee to hoof (0.76, P<0.01), and hind knee to hoof (0.60, P<0.01) were all highly correlated with body weight. The front leg length (0.35, P>0.05) was not correlated to the body weight.

Table 3.1: The effect of subspecies (Damara vs Karoo) and sex on the carcass and offal yield in kg and %

(Least square means ± SE)

Offal		Damara Male n=10	Damara Female n=10	Karoo Male n=10	Karoo Female n=10	P-*value* Sub species	P-*value* Sex	P-*value* Sub X Sex
Dead weight	kg	43.33^{a}±0.868	36.01^{b}±0.804	32.04^{c}±0.868	26.81^{d}±0.660	<0.001	<0.001	0.519
Cold carcass	kg	25.11^{a}±0.552	19.87^{b}±0.645	18.45^{b}±0.502	14.53^{c}±0.312	<0.001	<0.001	0.342
Dressing	%*	57.9^{a}±0.643	54.2^{b}±0.680	57.66^{a}±0.988	54.28^{b}±0.740	0.752	<0.001	0.984
Head	kg	3.19^{a}±0.079	2.10^{c}±0.034	2.46^{b}±0.065	1.49^{d}±0.045	<0.001	<0.001	0.319
	%*	7.4^{a}±0.211	5.9^{b}±0.088	7.7^{a}±0.234	5.6^{b}±0.181	0.766	<0.001	0.182
Tongue	kg	0.10^{a}±0.005	0.10^{a}±0.006	0.09^{a}±0.003	0.07^{b}±0.004	<0.001	0.038	0.064
	%	0.2^{a}±0.014	0.3^{a}±0.018	0.3^{a}±0.013	0.3^{a}±0.018	0.508	0.431	0.075
Skin	kg	2.46^{a}±0.085	1.83^{b}±0.054	1.95^{b}±0.105	1.35^{c}±0.000	<0.001	<0.001	0.819
	%	5.7^{a}±0.167	5.1^{b}±0.082	6.0^{a}±0.321	5.4^{ab}±0.090	0.194	0.026	0.828
Legs	kg	1.16^{a}±0.015	0.97^{b}±0.030	0.84^{c}±0.018	0.68^{d}±0.019	<0.001	<0.001	0.508
	%	2.7^{ab}±0.052	2.7^{a}±0.056	2.6^{ab}±0.043	2.5^{b}±0.061	0.038	0.764	0.511
Total external offal	kg	6.81^{a}±0.107	4.94^{b}±0.104	4.47^{b}±0.351	2.58^{c}±0.186	<0.001	<0.001	0.801
	%	15.7^{a}±0.245	13.5^{b}±0.200	13.9^{ab}±1.013	9.7^{c}±0.878	<0.001	<0.001	0.165
Heart	kg	0.33^{a}±0.012	0.28^{b}±0.009	0.29^{ab}±0.005	0.25^{c}±0.004	<0.001	<0.010	0.917
	%	0.8^{b}±0.022	0.7^{b}±0.022	0.9^{a}±0.029	0.9^{a}±0.020	<0.001	0.483	0.736
Lungs	kg	0.56^{a}±0.041	0.54^{a}±0.022	0.45^{b}±0.024	0.43^{b}±0.018	<0.001	0.332	0.884
	%	1.3^{b}±0.086	1.5^{a}±0.063	1.4^{ab}±0.071	1.6^{a}±0.057	0.151	0.014	0.857
Liver	kg	0.63^{a}±0.021	0.52^{b}±0.014	0.51^{b}±0.014	0.47^{c}±0.018	<0.001	<0.001	0.163
	%	1.5^{c}±0.045	1.5^{c}±0.042	1.6^{b}±0.045	1.7^{a}±0.044	<0.001	0.244	0.217
Kidneys	kg	0.14^{a}±0.003	0.12^{b}±0.003	0.09^{c}±0.008	0.09^{c}±0.002	<0.001	0.043	0.021
	%	0.3^{a}±0.007	0.3^{a}±0.011	0.27^{b}±0.023	0.33^{a}±0.008	0.172	0.022	0.045
Spleen	kg	0.06^{a}±0.002	0.06^{ab}±0.003	0.05^{b}±0.003	0.04^{c}±0.002	<0.001	0.011	0.621
	%	0.1^{a}±0.004	0.2^{a}±0.006	0.2^{a}±0.009	0.2^{a}±0.009	0.416	0.249	0.472
GIT	kg	7.41^{a}±0.261	7.88^{a}±0.336	4.67^{b}±0.395	5.22^{b}±0.277	<0.001	0.070	0.759
	%	17.1^{bc}±0.690	22.0^{a}±1.165	14.6^{c}±1.224	19.6^{ab}±1.114	0.066	<0.001	0.744
Total internal offal	kg	9.14^{a}±0.242	9.57^{a}±0.337	6.11^{b}±0.414	6.53^{b}±0.288	<0.001	0.122	0.878
	%	21.1^{a}±0.623	26.3^{b}±1.044	19.2^{a}±1.289	24.5^{b}±1.169	0.159	<0.001	0.693
Total Offal	kg	15.98^{a}±0.255	14.55^{b}±0.320	10.63^{c}±0.576	9.13^{d}±0.352	<0.001	<0.001	0.97

$^{a-d}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.
*Percentage of the dead weight

Table 3.2 Damara and Karoo springbok body measurements per male and female (Least square Means ± SE) *.

Measurement (cm)	Damara		Karoo		P-*value*		
	Male n=10	Female n=10	Male n=10	Female n=10	Sub Species	Sex	Sub X Sex
Body length	86.63^{a}±0.750	81.36^{b}±0.849	76.56^{c}±0.699	72.44^{d}±0.998	<0.001	<0.001	0.779
Body depth	36.79^{a}±0.65	34.9^{b}±0.510	33.39^{b}±0.331	31.78^{c}±0.364	<0.001	<0.01	0.933
Shoulder	4.08^{a}±0.369	3.27^{b}±0.132	3.00^{b}±0.220	2.25^{c}±0.094	<0.001	<0.01	0.99
Pin to Pin	15.89^{b}±0.387	17.86^{a}±0.597	16.06^{b}±0.386	16.61^{ab}±0.298	0.246	0.015	0.138
Neck	42.62^{a}±1.408	28.93^{c}±0.377	39.17^{b}±0.890	27.06^{c}±0.282	<0.01	<0.001	0.452
Front Leg length	84.23^{a}±0.757	61.83±^{b}17.785	74.14^{ab}±0.948	70.00^{ab}±0.494	0.970	0.017	0.049
Hind leg length	90.97^{a}±0.743	87.98^{a}±1.734	79.88^{b}±0.594	76.8^{c}±0.774	<0.001	<0.01	0.945
Front knee to hoof	32.44^{a}±0.312	31.38^{a}±0.453	28.8^{b}±0.260	28.45^{b}±0.621	<0.001	0.178	0.598
Hind knee to hoof	37.51^{a}±1.445	37.33^{a}±0.692	34.14^{b}±0.319	32.80^{b}±0.638	<0.001	0.289	0.352

* Measurements according to Figure 3.1

$^{a-d}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.

3.5: Pearson's correlation matrix for body weight and linear body measurements of Damara and Karoo springbok

	Body length	**Body depth**	**Shoulder to**	**Pin-Pin**	**Neck circumference**	**Shoulder to hoof**	**Pin to hoof**	**Front knee**	**Hind knee to**
Body Weight	0.96	0.85	0.66	0.04	0.61	0.35	0.9	0.76	0.6
	<0.01	<0.01	<0.01	0.8	<0.01	0.05	<0.01	<0.01	<0.01
Body length		0.83	0.65	0.03	0.55	0.3	0.88	0.71	0.61
		<0.01	<0.01	0.84	<0.01	0.11	<0.01	<0.01	<0.01
Body depth			0.63	0	0.52	0.37	0.82	0.67	0.67
			<0.01	1	<0.01	0.05	<0.01	<0.01	<0.01
Shoulder to shoulder				-0.02	0.54	0.09	0.63	0.47	0.56
				0.9	<0.01	0.66	<0.01	0.01	<0.01
Pin to Pin					-0.36	-0.17	0.12	0.14	-0.12
					0.02	0.39	0.53	0.46	0.54
Neck circumference						0.47	0.53	0.36	0.37
						0.01	<0.01	0.06	0.00
Shoulder to hoof							0.24	0.16	0.05
							0.2	0.39	0.69
Pin to hoof								0.8	0.73
								<0.01	<0.01
Front knee to hoof									0.39
									0.03

3.3.2 Intensity of culling comparison (Trial 2)

3.3.2.1 Offal weights

The effect of intensity of culling and sex on offal weight in kg and as a percentage of the dead weight is presented in Table 3.3, where there was significant interactions between intensity of culling and sex for the live weight (P=0.028) and cold carcass weight (P=0.034). Male springbok from Wellington had significantly heavier dead weights and carcass weights than males from Witsand where there was intense selective culling. There was no significant difference between females from Wellington and females from Witsand for dead weight. Wellington males also had significantly heavier cold carcass weights compared to Wellington females, Witsand males and Witsand females. Dressing percentage had significant sex (P<0.01) and intensity of culling (P<0.001) effect; Witsand males had a higher dressing percentage than Wellington males, Wellington females and Witsand females.

Wellington males differed significantly from all treatment groups and had the heaviest skin weight, while the other treatment groups did not differ from each other. All other external offal parameters had significant interaction between the intensity of culling and sex: head (P=0.002), tongue (P=0.002) and legs (P=0.029). There was no significant difference between females for Wellington and Witsand for head weight, but Wellington male heads were significantly heavier than Witsand males, and both female groups. Witsand males and females did not differ significantly for tongue, skin and leg weights. The Wellington males had significantly heavier tongue weights than all other treatment groups, while the other treatment groups did not differ significantly from each other. Leg weights differed significantly between Wellington males and Wellington females but did not differ between Wellington males and Witsand males or between Wellington females and Witsand females.

The Witsand males and females did not differ significantly for heart, lung, liver, kidneys, spleen or GIT weights and percentages (Table 3.3). The Wellington males had significantly heavier hearts than the Wellington females and Witsand animals. The Wellington males and females showed no significant difference for lung weight, but the Wellington males had significantly heavier lungs than the Witsand males. There was no significant difference between any of the groups for liver weights and there was no significant difference between Wellington males and females for kidney weights, although kidney weights of the Wellington animals were significantly heavier than the Witsand animals. The GIT was significantly heavier in the Wellington animals than in the Witsand animals. There was no significant difference between Witsand and Wellington males for the external, internal and total offal weights. The females from each farm did differ significantly for the internal and external offal weights but did not differ significantly for the total offal weight. There was a significant difference between sexes on each farm for the external offal weight but not for the internal or total offal weight.

Table 3.3: The effect of intensity of culling on the carcass yield and offal yield in kg and %, per male and female Karoo springbok (Least square means ± SE)

		Wellington (low intensity)		**Witsand (high intensity)**		**P-*value***		
Offal		**Male n=10**	**Female n=10**	**Male n=10**	**Female n=10**	**Cull**	**Sex**	**Cull X Sex**
Dead weight	kg	32.04^{a}±0.868	26.81^{b}±0.660	25.26^{b}±1.355	24.62^{b}±0.893	<0.01	<0.01	0.028
Cold carcass	kg	18.45^{a}±0.502	14.53^{b}±0.312	15.52^{b}±0.950	14.32^{b}±0.567	0.132	<0.001	0.034
Dressing	%*	57.7^{b}±0.988	54.3^{c}±0.740	61.3^{a}±1.555	58.2^{b}±0.939	<0.001	<0.01	0.919
Head	kg	2.46^{a}±0.065	1.49^{c}±0.045	1.94^{b}±0.116	1.47^{c}±0.044	<0.01	<0.001	<0.01
	%	7.7^{a}±0.234	5.6^{b}±0.181	7.7^{a}±0.160	6.1^{b}±0.312	0.489	<0.001	0.294
Tongue	kg	0.09^{a}±0.003	0.07^{b}±0.004	0.06^{b}±0.006	0.07^{b}±0.002	<0.01	0.045	<0.01
	%	0.3^{a}±0.013	0.3^{a}±0.018	0.3^{a}±0.013	0.3^{a}±0.011	0.602	0.976	0.070
Skin	kg	1.95^{a}±0.105	1.35^{b}±0.000	1.63^{b}±0.105	1.43^{b}±0.057	0.304	<0.01	0.064
	%	6.0^{ab}±0.321	5.4^{b}±0.09	6.4^{a}±0.127	5.8^{b}±0.178	0.300	0.011	0.883
Legs	kg	0.84^{a}±0.018	0.68^{b}±0.019	0.78^{ac}±0.032	0.72^{bc}±0.009	0.644	<0.001	0.029
	%	2.6^{b}±0.043	2.5^{b}±0.061	3.1^{a}±0.078	3.0^{a}±0.088	<0.001	0.112	0.583
Total external	kg	4.47^{a}±0.351	2.58^{c}±0.186	4.35^{a}±0.250	3.62^{b}±0.072	0.371	<0.001	0.012
Heart	kg	0.29^{a}±0.005	0.25^{b}±0.004	0.22^{c}±0.016	0.23^{bc}±0.009	0.014	0.152	<0.01
	%	0.9^{a}±0.029	0.9^{a}±0.020	0.9^{a}±0.062	0.9^{a}±0.026	0.352	0.190	0.436
Lungs	kg	0.45^{a}±0.024	0.43^{ab}±0.018	0.39^{b}±0.027	0.41^{ab}±0.015	0.049	0.550	0.161
	%	1.4^{b}±0.071	1.6^{ab}±0.057	1.5^{ab}±0.079	1.7^{a}±0.074	0.507	0.083	0.974
Liver	kg	0.51^{a}±0.014	0.47^{a}±0.018	0.50^{a}±0.028	0.46^{a}±0.028	0.780	0.098	0.727
	%	1.6^{c}±0.045	1.7^{bc}±0.044	2.0^{a}±0.053	1.9^{ab}±0.078	<0.01	0.777	0.075
Kidneys	kg	0.09^{b}±0.008	0.09^{b}±0.002	0.13^{a}±0.007	0.13^{a}±0.008	<0.001	0.644	0.530
	%	0.3^{b}±0.023	0.3^{b}±0.008	0.5^{a}±0.017	0.5^{a}±0.030	<0.001	0.046	0.105
Spleen	kg	0.05^{a}±0.003	0.041^{ab}±0.00	0.04^{b}±0.004	0.04^{ab}±0.003	0.723	0.549	0.183
	%	0.2^{a}±0.009	0.2^{a}±0.009	0.16^{a}±0.015	0.2^{a}±0.013	0.229	0.400	0.757
GIT	kg	4.67^{a}±0.395	5.22^{a}±0.277	3.26^{b}±0.437	3.39^{b}±0.227	0.022	0.187	0.373
	%	14.6^{b}±1.224	19.6^{a}±1.114	12.5^{b}±1.503	13.9^{b}±1.082	0.304	<0.01	0.085
Total internal	kg	6.11^{ab}±0.414	6.53^{a}±0.288	4.53^{b}±0.495	4.66^{b}±0.238	0.026	0.293	0.520
Total offal	kg	10.63^{a}±0.576	9.13^{ab}±0.352	8.94^{ab}±0.697	8.35^{b}±0.264	0.204	0.061	0.404

$^{a-c}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.

* Percentage is calculated as the percentage of the dead weight

3.3.2.2 Body dimensions and correlations

The effect of over-culling (Witsand) in comparison to controlled culling (Wellington) on body measurements (cm) is presented in Table 3.4 and correlations between linear body measurements and deadweight is presented in Table 3.5. There were no significant interactions between the intensity of culling and sex on any of the body measurement parameters. The Witsand males and females did not differ significantly for any, body dimension parameter. On the other hand, the Wellington males had a significantly longer body length than Wellington females, Witsand females and Witsand males. Wellington males also had a significantly deeper body depth than Witsand males, Witsand females, and Wellington females. The Wellington males also had a significantly longer front and hind leg lengths than the Wellington females and Witsand animals. There was no significant difference for front knee to hoof length but the hind knee to hoof length did differ significantly between male and female Wellington animals. Body length (0.82, P<0.01), body depth (0.75, P<0.01), front (0.77, P<0.01) and hind (0.63, P<0.01) leg length, and front knee to hoof length (0.42, p<0.01) were all highly correlated to body weight (Table 3.6).

Table 3.4: The effect of intensity of culling on the linear body measurements (cm) per male and female Karoo springbok (Least square means ± SE)

	Wellington (low intensity)		**Witsand (high intensity)**		**P-*value***		
Linear Parameter	**Male n=10**	**Female n=10**	**Male n=10**	**Female n=10**	**Cull**	**Sex**	**Cull X Sex**
Body length	71.78^{b}±1.412	72.25^{b}±0.797	76.56^{a}±0.699	72.44^{b}±0.998	0.016	0.041	0.015
Body depth	29.5^{c}±0.618	30.20^{c}±0.359	33.39^{a}±0.331	31.78^{b}±0.364	<0.001	0.142	<0.01
Shoulder	3.56^{a}±0.403	2.75^{a}±0.688	3.00^{a}±0.220	2.25^{a}±0.094	0.336	0.146	0.914
Front Leg length	66.70^{c}±1.353	65.12^{c}±0.701	74.14^{a}±0.948	70.00^{b}±0.494	<0.001	<0.01	0.87
Hind leg length	70.29^{c}±1.567	74.77^{b}±0.546	79.88^{a}±0.594	76.8^{b}±0.774	<0.001	0.680	<0.001
Front knee to hoof	28.3^{a}±0.333	27.44^{a}±0.508	28.8^{a}±0.260	28.45^{a}±0.621	0.386	0.127	0.835
Hind knee to hoof	33.92^{ab}±0.479	33.65^{ab}±0.297	34.14^{a}±0.319	32.80^{b}±0.638	0.856	0.082	0.224

$^{a-c}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.

Table 3.5: Pearson's correlation matrix for body weight and linear body measurements of springbok from Witsand and Wellington

	Body length	Body depth	Shoulder to shoulder	Shoulder to hoof	Pin to hoof	Front knee to hoof	Hind knee to hoof
Bodyweight	0.82	0.75	0.32	0.77	0.63	0.42	0.28
	<0.01	<0.01	0.06	<0.01	<0.01	<0.01	0.08
Body length		0.62	0.25	0.68	0.53	0.30	0.47
		<0.01	0.013	<0.01	<0.01	0.07	<0.01
Body depth			0.00	0.70	0.65	0.21	0.16
			0.99	<0.01	<0.01	0.20	0.35
Shoulder to shoulder				-0.03	-0.14	0.12	0.11
				0.87	0.42	0.46	0.53
Shoulder to hoof					0.77	0.45	0.31
					<0.01	<0.01	0.05
Pin to hoof						0.24	0.26
						0.14	0.11
Front knee to hoof							-0.11
							0.49

3.4 DISCUSSION

3.4.1 Subspecies comparison (Trial 1)

South African farms frequently make use of Namibian springbok (Damara and Kalahari) in breeding programs in the hope of increasing body size of the Karoo subspecies. It is thought that the Damara and Kalahari springbok are significantly larger than the Karoo springbok and by hybridising the Namibian springbok with Karoo the progeny will be larger/heavier than its Karoo parent. Differences in dead weights between Namibian and Karoo springbok have long been observed by hunters and game meat processors. These differences are also apparent in the current study where Damara springbok had a pooled dead weight of 39.98 kg and Karoo springbok had a pooled dead weight of 29.43 kg. These differences in dead weight are similar to differences found in literature where Namibian springbok (*A. m. hofmeyri)* had a dead weight of 38.53 kg (Hoffman, van Schalkwyk, & McMillin, 2019) and Karoo springbok had a dead weight of 30.2 kg (Kroucamp, 2004; Van Zyl & Ferreira, 2004).

Damara subspecies had a pooled cold carcass weight of 22.61 kg in comparison to 16.43 kg for Karoo springbok. These differences in cold carcass weight are similar to the cold carcass weights observed for Namibian springbok (Hoffman *et al*., 2019) and Karoo springbok

(Van Zyl & Ferreira, 2004). There is some debate as to whether the differences observed between subspecies weights are due to differences in nutrition brought on by differences in habitat (Furstenburg, 2016) or due to genetic differences (Van Aswegen *et al*., 2012).

Body measurements have a linear correlation with bodyweight and as body weight increases, body measurements increase the (Agamy *et al*., 2015). The Damara subspecies had significantly larger body dimensions than the Karoo subspecies for all the linear measurements (body length, body depth, neck circumference, hind leg length, front knee to hoof and hind knee to hoof).

Game offal is an under-utilised protein source that adds to the edible portion of the carcass and could be a valuable food source to the most vulnerable of South African citizens (McCrindle *et al*., 2013); its importance should thus not be overlooked. The edible internal offal portion consists of the liver, lungs, kidneys, heart, and tripe. The Damara subspecies had heavier heart, lungs, liver, and kidneys than the Karoo subspecies. The edible portion of the external offal consists of the head and feet. The Damara subspecies had heavier head and feet than the Karoo subspecies. Tripe was the only edible offal parameter that cannot be determined in this study as the empty GIT weight was not measured. The GIT is defined in this study as the full stomach including all intestines. The GIT showed the highest contribution to the offal yield of all the measured parameters, similar to Van Zyl & Ferreira (2004). There was a significant difference between the subspecies for GIT weight. The GIT is a notable confounding factor in terms of live weight and dressing percentage calculations and comparisons. The animals are harvested in extensive situations where there is no control over *ante mortem* feeding (Hoffman, Mostert, Kidd, & Laubscher, 2009). The highest GIT weight was recorded in the male and female Damara group and this could be the reason for the higher live weight of the female Damara animals when compared to the male Karoo animals. The Damara female animals' GIT made a higher contribution (%) to the live weight than the Karoo males, whereas there was no significant difference in the GIT contribution to live weight between the male Damara and Karoo animals. This could also explain the lack of significant differences in the heart, liver, spleen, tongue, and skin for the Damara female and Karoo male groups as offal seems to be positively correlated with live weight (Tables, 3.5 & 3.6; Agamy *et al*, 2009).

When sexual maturity is reached, it is expected that males would have heavier dead weights compared to females of equal ages (Jooste, Conroy, & Fairall, 1990). The sexual dimorphism within the Damara subspecies contrasts with Hoffman *et al.* (2019) where it was observed that adult Namibian springbok had no significant difference in dead weight between males (40.44 kg) and females (36.61 kg). Although there was a strong trend towards the males having a heavier dead weight, as the differences in weight between Namibian springbok was

6kg. This is a very similar difference to the current study. The significant sex effect for the Karoo subspecies is similar to Kroucamp (2004) where significant sex differences were observed between male and female Karoo springbok, but contrast with Van Zyl & Ferreira (2004) who observed that Karoo males did not differ significantly from females for dead weight. Differences between sexes within the Damara subspecies are similar to Hoffman *et al.* (2019) where differences between male and female Namibian springbok cold carcass weights were observed. For the Karoo subspecies, differences between males and females contrast with Van Zyl & Ferreira (2004) where no differences between male and female cold carcass weights were observed. There was a sex effect ($p<0.01$; Table 3.1) for dressing percentage. Male springbok had a higher dressing percentage at 57.8% than female springbok at 54.3%. The sex effect observed in the present study is in accordance with Kroucamp (2004) but is in contrast with Hoffman *et al.* (2019) and Van Zyl & Ferreira (2004) where no significant sex-related effects were found. It should be considered that Van Zyl & Ferreira had a very small sample size (5 males; 3 females) that could have influenced the sexual dimorphism determination. The age of the springbok could also have influenced the results as the determination of springbok age can be challenging, as it is strongly dependent on the vegetation surrounding them consumed. Differences between sexes generally only become apparent in adult springbok. The quantification of the effect of age (at different defined intervals) per sex on the dead weight has yet to be thoroughly determined for springbok and so springbok are generally divided into adult and sub adult groups. The exact age weight relationship per sex is not yet known and does make comparison between studies difficult. The springbok examined by Van Zyl & Ferreira (2004) were between 17 - 36 months old and the Namibian springbok studied by Hoffman *et al.* (2019) were 18 - 24 months old. Springbok are classified as adult from the age of ~18 months. This is generally the youngest age that is hunted. The current studies' springbok ranged from 18 months to 5 years. This classification of adult is very similar to that of Kroucamp (2004) where springbok from age 2 - 5 years were classed as adult. This could be the reason that differences observed between males and females for both Damara and Karoo subspecies coincided closely with findings by Kroucamp (2004) but frequently contrast with Van Zyl & Ferreira (2004) and Hoffman *et al.* (2019).

The differences observed between Damara and Karoo springbok were apparent in dead weight, cold carcass weight, and many organs and body measurement traits. It would also seem that these are differences that are in proportion to each subspecies' body weight and thus the differences observed in dead weigh cannot be attributed to differences in internal or external offal weights. This is further substantiated by differences observed in carcass weights. As body weight and many linear body measurements are highly correlated (Table 3.5), the differences in physical size, body length and depth contribute significantly to the differences in body weight that is observed between subspecies. There is a notable difference between the Damara subspecies and Karoo subspecies for the same sex, but these differences are not so significant between the Damara females and the Karoo males.

3.4.2 Intensity of culling (Trial 2)

For successful mating of a springbok population a 1:1 female-to-male ratio is not necessary, a 30:1 ratio is considered the maximum females for every male needed for successful breeding. As farms do not need as many males as females there are frequently surplus males that must be culled. Surplus males tend to congregate while breeding males are solitary (Skinner & Louw, 1996). Males have been selectively targeted for two reasons, the first being trophy hunting. Horn size is a sought-after attribute by hunters; thus, hunters frequently target the larger horned rams for trophies. Trophy hunting is one of the highest-earning sectors of the game industry (Taylor, Lindsey, Davies-Mostert, *et al*., 2016). The selective culling of large horn males could in time decrease the length of horns within the population (Coltman *et al*., 2003; Festa-Bianchet, Pelletier, Jorgenson, Feder, & Hubbs, 2014). The second reason males have been more selectively targeted than females, is the custom that hunters pay per animal and not per carcass weight. This has led to hunters targeting the largest springbok when hunting. This decreases the number of adult males and thus the average age of the male population. Recently the custom has started to change with more farms charging per carcass weight, and so body size of springbok has become increasingly important. The Witsand farm is an example where over culling has taken place over the last eight years and the largest males were specifically targeted while the Wellington farm has had very little hunting activity over the same period. A common phenomenon in intensively culled populations where one sex is selectively removed, is the decrease in the average body size of that sex in the population (Coltman *et al*., 2003; Fenberg & Roy, 2008). This is very apparent on the Witsand farm as Wellington males had heavier dead weights and cold carcass weights than Witsand males. The Wellington females and Witsand females did not differ for dead weights and cold carcass weights. Offal as previously discussed is correlated to bodyweight, but in this study no differences were found between Wellington males and Witsand males for the offal parameters. Dead weight differences could not have been large enough for offal differences to exist. The Wellington males had significantly larger body dimensions than Witsand males for all the linear measurements (body length, body depth, front and hind leg length) that were highly correlated to body weight. The Wellington and Witsand females showed very little difference in linear body measurements.

Certain male-female differences exist for springbok; male springbok have been noted to have heavier dead weights, carcass weights and dressing percentages than females (Jooste *et al*., 1990; Kroucamp, 2004). In this study, it was found that male and female differences existed on the Wellington farm for dead weight, carcass weight and all linear body measurements (body length, body depth, and front leg length) that were highly correlated with body weight. These differences did not exist between males and females of the Witsand farm. The Witsand farm did differ for head weights between males and females as would be expected within a springbok herd as males have significantly larger horns than females. Although male and female differences were apparent for head weight on the Witsand farm, the Witsand males still had significantly lighter head weights than the Wellington males.

3.5 CONCLUSION

There are definitive differences in terms of dead weight, carcass weight, offal weight and body measurements between Damara and Karoo subspecies. The Damara subspecies have larger linear body dimensions, they have heavier dead weights, heavier cold carcass weights, and heavier total offal weights. They are in short, much larger animals than the Karoo subspecies. The Damara subspecies only have similar dressing percentages to the Karoo subspecies.

High intensity culling of springbok populations, especially the selective hunting of large males decreases the linear body measurements and thus the dead weight and carcass weights of the males within that population. The male population of an over-culled population no longer differ from females of that population in terms of deadweight and carcass weight. The culling of surplus males has always been economically beneficial as there are fewer males than females necessary for successful mating and so culling of surplus springbok males does not negatively influence population growth. The over-culling of large mature males and subsequent decrease in surplus male size has very real economic implications as these males no longer have the benefit of being significantly larger than females. The deadweight and carcass weight decreasing effect that intensity of culling has on the male springbok of a herd should be considered in the management of a springbok herd.

Both subspecies size differences (Trial 1) and the decreasing of male springbok size in intensively culled populations (Trial 2) could have significant economic implications for farmers when springbok are paid for per weight and not per animal. The rather drastic differences in carcass weights also serve as a motivator for Namibian farmers to charge per carcass weight and not per animal.

Further studies on the correlation of horn size and body weight as well as the effect of over culling on the horn growth could be conducted to form a better picture of the negative implications that over-culling could have on a springbok herd and with this, the very real negative economic implications.

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CHAPTER 4

INFLUENCE OF SUBSPECIES, SEX AND INTENSITY OF CULLING ON THE YIELD OF SPRINGBOK (*ANTIDORCAS MARSUPIALIS*) CARCASSES.

ABSTRACT

This study determined the influence of subspecies, sex and intensity of culling on the carcass-cut composition (neck, forelimb, ventral trunk, dorsal trunk and back leg) and primal composition (bone, lean meat, fat and waste) of springbok. The Damara subspecies had heavier dead weight and carcass weight in comparison to the Karoo subspecies. The Damara subspecies also had a heavier neck, forelimb, ventral trunk, dorsal trunk and back leg weights than the Karoo subspecies. However, the percentage contribution of each primal to the cold carcass weight did not differ significantly between Damara and Karoo subspecies except for the forelimb and ventral trunk. The Damara subspecies had a higher percentage of forelimb and a lower percentage ventral trunk than the Karoo subspecies. Sex differences for the percentage contribution to cold carcass weight of the neck and forelimb existed; female springbok had a higher percentage contribution to the cold carcass weight for the dorsal trunk, ventral trunk and back leg. Male springbok had a higher lean meat percentage, and female springbok had a higher fat percentage. In the intensity of culling trial (Trial 2), the Wellington male springbok had the heaviest dead weight and the Wellington females, Witsand males and Witsand females had similar lower dead weight and cold carcass weights. Wellington (low intensity) springbok had a higher percentage contribution for the forelimb and ventral trunk in comparison to Witsand springbok (high intensity). The Wellington springbok also had higher meat and lower bone composition for the forelimb and ventral trunk than the Witsand springbok.

***Keywords*:** Carcass composition, meat, bone, fat, subspecies, springbok, sex

4.1 INTRODUCTION

In developing countries, such as South Africa, population growth, economic growth and conservation are ever-present challenges. South Africa still has a positive population growth (United Nations, 2019). The pressure that population growth places on the economy and environment of such countries is enormous (Cropper & Griffiths, 2007). Increases in population number increases the pressure to produce sufficient food while not destroying the environment (Hall, Dawson, Macdiarmid, Matthews, & Smith, 2017). Farming practices with domestic animals have increased the production outputs as a response to increased demand for animal protein of an ever-growing global population (Cao & Li, 2013). However, game animals are better adapted to the arid areas of South Africa and occur in many instances where domestic animals cannot thrive or even survive. Game animals such as springbok are specially adapted to go without water for long periods and so can thrive in drought-stricken areas under conditions which domestic animals would not survive (Bigalke, 1972). Game meat can play a unique role in aiding the problems of food security in South Africa (van Vliet, Nebesse, Gambalemoke, Akaibe, & Nasi, 2012), but is not without challenges (Cawthorn & Hoffman, 2015).

The game farm industry is also of economic and conservation importance (Saayman, Van der Merwe, & Rossouw, 2011). There have been significant increases in live-sale prices received at auctions over the last two decades; the price of springbok has increased 200% in 10 years, and the game industry experienced a 100% increase in price for game (Carruthers, 2008; Van der Merwe & Saayman, 2003). The amount of wildlife, as well as the diversity of wildlife on privately owned land, has also increased in the last two decades (Barnes & De Jager, 1996). The economic incentive of the game industry has increased the occurrence of land used for game farming and thus increased their conservation potential (Lindsey, 2008; Lindsey, Roulet, & Roman, 2007; Minin, Leader-williams, & Bradshaw, 2020), by not only increasing the number of game but the diversity as well (Barnes & De Jager, 1996). The industry is made up of four primary components, namely; trophy hunting, breeding, ecotourism and processed products (Van der Merwe, Saayman, & Krugell, 2004). Live sales and high-quality meat sales give a better return than trophy hunting when evaluated on a systemic level (Berry, 1986).

Carcass weights are good indicators of meat production potential (Von la Chevallerie, 1970). Species differ significantly in terms of growth rate, body weight and body composition (Black, 1988). The differences in muscle and fat distribution between species are significant as they determine the differences between species for high priced anatomical regions that could be exploited (Berg, 1968a). Springbok has a higher dressing percentage than most domestic animals and are very prolific breeders (Bigalke, 1972). Springbok and indigenous sheep breeds have similar gestation periods and dressing percentages (Tshabalala, Strydom, Webb, & De Kock, 2003; Van Zyl & Ferreira, 2004). The production of springbok has very few geographical limitations as they are highly adapted to a multitude of environments as supported by the prevalence of springbok on game farms across South Africa (Bigalke, 1972; Taylor, Lindsey, & Davies-Mostert, 2016; Van Zyl & Ferreira, 2004). Springbok body weights, carcass weights and offal, have been researched. The research to date focused on main effects such as sex, age and production region (Kroucamp, 2004; Van Zyl & Ferreira, 2004) and how these influence yields and thus production potential. Most research has been conducted on the Karoo subspecies, and no research has been done concerning the Damara subspecies which is said to be the larger of the springbok sub-species. There is also no research available on the carcass composition in terms of meat: bone: fat: waste of each primal cut for either Karoo or Damara subspecies.

The aim of this research chapter is first to determine if there is a difference in the primal cuts (neck, shoulder, dorsal trunk, ventral trunk, hind leg, back shank and front shank) to cold carcass weight between subspecies (Damara vs Karoo). Secondly, to determine whether body composition (meat: bone: fat: waste) differences exist between the two subspecies. Thirdly, to determine the difference between high-intensity culling and low-intensity culling on the carcass yields of the seven primary portions (neck, shoulder, dorsal trunk, ventral trunk, hind leg, back shank, and front shank) and their composition (meat: bone: fat: waste) of both males and females Karoo springbok.

4.2 METHODS AND MATERIALS

4.2.1 Animals and Study location

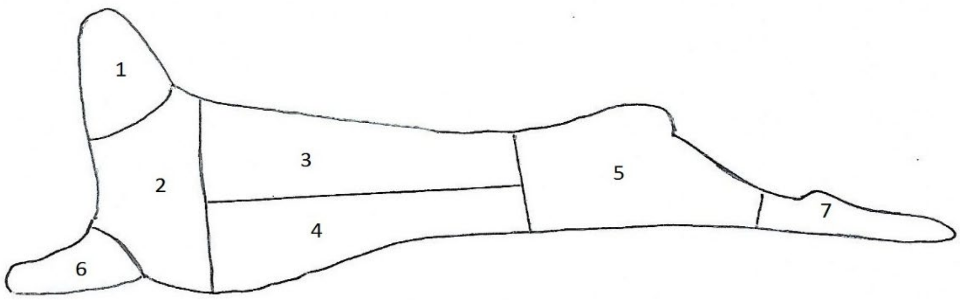
Trial 1 (Subspecies comparison) consisted of 40 springbok; 20 Damara (*A. m. angolensis*) and 20 Karoo (*A. m. marsupialis,* Wellington); 50% being males and 50% females. Trial 2 (intensity of harvesting comparison) was made up of the same 20 Karoo springbok from Wellington (low intensity) and 20 Karoo springbok from Witsand (high intensity). Age of animals was determined by wear and tear of teeth (Dewar *et al.*, 2006*).* Age of animals was determined by wear and tear of teeth (Dewar, Halkett, Hart, Orton, & Sealy, 2006). Damara and Karoo (Wellington) springbok were between 18 months and five years old. Karoo springbok from Witsand ranged in age between 12 month and 2 years old. For a more detailed description of each farm refer to Chapter 3 section 3.2.1.

4.2.2 Culling and Dressing

The animals were harvested in the same fashion on each of the three farms. Animals were shot in the head with a .243 rifle (Ethical Clearance Number: 10NP_HOF02), and then exsanguinated within two minutes of killing. The field notes reported that the Karoo subspecies, culled on the Wellington farm had a high occurrence of high neck shots caused by the distance that the shots needed to be taken from, whereas all Damara springbok were culled with head shots. A more detailed description of the evisceration can be found in Chapter 3 section 3.2.2. Following evisceration, the carcasses were loaded into the chiller at a temperature of 4°C.

4.2.3 Sample preparation

Carcasses were removed from the chiller unit 24 hours after they had been placed there (Day 2 *post mortem*). The left side of the carcass was divided into seven primary portions as illustrated in Figure 4.1. Firstly, the neck was removed, separating the neck from the trunk after the 7th cervical vertebrae. Carcasses were then halved along the dorso-ventral plane with a band saw. The right side of the carcass was used for physical meat quality (Chapter 5) and chemical composition (Chapter 6) determination. The left side was divided into the forelimb, ventral trunk, dorsal trunk and back leg. The forelimb was removed next by cutting from the *humeral/scapular* junction to the caudal bend along the *supraspinatus* and cartilage of the *scapula*. Fromm the caudal bend a straight cut was made towards the *radius* and *ulna*. The hind leg was severed from the trunk between the last lumbar and first sacral vertebrae. The dorsal and ventral trunks were then separated along a line drawn from the junction of the sternum and first rib to the centre of the tenth rib. The flank was thus included in the ventral trunk and the thick rib was thus included in the dorsal trunk. The shank of the forelimb and hind limb were separated from the forelimb and hind limb with a band saw.



1. Neck
2. Shoulder
3. Dorsal trunk
4. Ventral trunk
5. Hind leg
6. Front shank
7. Back shank

Figure 4.1: Illustration of cutting test primary portion positions according to Casey (1982)

4.2.4 Cutting (Block) test

Each primal: cut, neck, shoulder, dorsal trunk, ventral trunk, hind leg, front and back shanks were then deboned and divided into meat, fat, bone and waste which was weighed for each primary portion. Waste was defined as trimmings and tendons that were not fit for human consumption and thus had no monetary value. Fat was defined as the combination of the subcutaneous and intermuscular fat. The following important muscles were removed: The *Infraspinatus* (IS) and *Supraspinatus* (SS) muscles were removed from the shoulder and weighed. The *Longissimus thoracis et lumborum* (LTL) muscle was removed from the dorsal trunk and weighed. The *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) muscles were removed from the hind leg and weighed.

4.2.5 Statistical analysis

Trial 1 had a 2x2 factorial design experimental layout with subspecies and sex as the two main effects. Trial 2 also had a 2x2 factorial experimental design with intensity of culling and sex as the main effects. A two-way ANOVA (univariate analysis of variance) was constructed using the General Linear Model (GLM) of STATISTICA to determine significant differences between main effects and a significant interaction of main effects for both Trial 1 and Trial 2. Statistical analysis was done using the Statistica 64 version 13.4 (2018) VEPAC model. Age was also included as a covariate in both Trial 1 and 2. Levene's test was conducted to test for deviation from homoscedasticity. A Shapiro-Wilk test was performed on the standardised residuals to test for the assumption of normality and determine if outliers were present. A significance level of 5% was used to determine significant differences

4.3 RESULTS

4.3.1 Subspecies comparison (Trial 1)

The effect of subspecies (Damara vs Karoo) and sex on the dead weight, carcass weight, dressing percentage and tissue yields are reported in Table 4.1, where the Damara males had heavier carcasses than Karoo males, and Damara females had heavier carcasses than Karoo females. A more detailed account of differences between Damara and Karoo dead weight, carcass weight and dressing percentage is described in Chapter 3. There were significant interactions for the total bone percentage ($P=0.024$), where the Damara male and female springbok had similar bone percentages, whereas the Witsand males had lower bone percentages than the Witsand females. Both Damara males and Karoo males had significantly higher meat percentages than Damara females and Karoo females. Female ($P<0.001$)

springbok had a higher percentage fat (subcutaneous and intermuscular) comparison to their male counterparts.

The effect of subspecies (Damara vs Karoo) and sex on the primal weight and percentage is presented in Table 4.2, where the Damara subspecies had heavier primal weights in comparison to the Karoo subspecies. There were subspecies (P=0.028) difference for the percentage contribution of the neck to the cold carcass weight; Karoo springbok had the higher neck percentage in comparison to their counterparts. For the shoulder, the Damara subspecies (P<0.01) had a higher shoulder percentage. Female springbok had a higher dorsal trunk (P<0.001), ventral trunk (P<0.001), hind leg (P<0.001) and back shin (P=0.036) percentage in comparison to male springbok. In contrast male springbok had a higher neck (P<0.001) and shoulder (P<0.001) percentage.

Table 4.1: The effect of subspecies (Damara vs Karoo) and sex on the carcass yield and tissue proportions (Least square means ± SE)

		Damara		Karoo		P-value		
Carcass yield		**Male N=10**	**Female N=10**	**Male N=10**	**Female N=10**	**Sub species**	**Sex**	**Sub X Sex**
Dead weight	Kg	43.93±1.007	36.93±0.921	32.60±1.007	26.70±0.898	<0.001	<0.001	0.519
Cold carcass	Kg	25.29±0.588	19.93±0.538	18.63±0.502	14.23±0.525	<0.001	<0.001	0.342
Dressing	%[1]	57.38±0.885	53.79±0.810	57.13±0.885	53.56±0.789	0.752	<0.001	0.984
	kg	19.64^{a}±0.471	14.88^{b}±0.426	14.62^{b}±0.487	10.21^{c}±0.449	<0.001	<0.001	0.677
Meat	%[2]	77.9^{a}±1.007	75.3^{bc}±0.912	77.5^{ab}±1.043	73.75^{c}±0.961	0.282	<0.01	0.525
	kg	4.79^{a}±0.100	3.74^{b}±0.0912	3.48^{c}±0.100	2.83^{d}±0.096	<0.001	<0.001	0.036
Bone	%[2]	19.0^{b}±0.448	19.0^{b}±0.406	18.5^{b}±0.464	20.4^{a}±0.428	0.287	0.035	0.024
	kg	0.31^{b}±0.089	0.69^{a}±0.081	0.16^{b}±0.092	0.39^{b}±0.085	0.01	<0.01	0.364
Fat	%[2]	1.3^{b}±0.465	3.4^{a}±0.421	0.9^{b}±0.481	2.9^{a}±0.443	0.263	<0.001	0.811

[1] Percentage calculated as the proportion of the dead weight
[2] Percentage calculated as the proportion of the cold carcass weight
[a-d] Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups.

The effect of subspecies (Damara vs Karoo) and sex on the tissue composition of the seven primals are presented in Table 4.3, where the Damara subspecies had a higher lean meat (P=0.011) percentage and lower waste (P<0.01) percentage than the Karoo subspecies for the neck primal. Male springbok had a higher meat (P<0.001) and lower bone (P<0.001) percentage for the neck.

There was significant interaction between subspecies and sex for the bone percentage (P<0.001) of the shoulder where the interaction for bone percentage was due to the Karoo males having a lower bone percentage than the Karoo females. In contrast, the

Damara males and females did not differ for bone percentage. The hind leg also had an interaction between subspecies and sex for the bone (P=0.044) percentage, where the Karoo females had a higher bone percentage than the Karoo males, whereas the Damara males and females had similar bone percentages.

There were no significant differences in the percentage of lean meat and bone between subspecies for the shoulder, front shank, dorsal trunk, ventral trunk, hind leg and back shank. Whereas, the fat percentage differed between sexes for the shoulder (P<0.001), dorsal trunk (P<0.001), ventral trunk (P=0.018) and hind leg (P<0.01), where females had a higher fat percentage than males.

The effect of subspecies (Damara vs Karoo) and sex on the muscle yields are presented in Table 4.6. The ST had a higher percentage in the Karoo subspecies (P<0.001). Female springbok also had a higher IS (P<0.001) and SS (P<0.001) percentage. Subspecies had no effect on the LTL, BF, IS and SS percentage.

Table 4.2: The effect of subspecies (Damara vs Karoo) and sex on the primal weight (kg) and primal percentage (%) (Least square means ± SE)

		Damara		Karoo		P-value		
Primal		**Male N=10**	**Female N=10**	**Male N=10**	**Female N=10**	**Sub species**	**Sex**	**Sub X Sex**
Neck	kg	2.31^{a}±0.107	0.90^{c}±0.098	1.79^{b}±0.107	0.79^{c}±0.095	<0.01	<0.001	0.031
	%	9.1^{ab}±0.411	4.6^{c}±0.376	9.6^{a}±0.411	5.6^{b}±1.197	0.028	<0.01	0.421
Shoulder	kg	6.95^{a}±0.209	4.64^{b}±0.191	4.69^{b}±0.209	3.13^{c}±0.186	<0.001	<0.001	0.040
	%	27.5^{a}±0.656	23.3^{c}±0.601	25.2^{b}±0.656	22.1^{c}±0.586	<0.01	<0.001	0.326
Front shank	kg	0.73^{a}±0.021	0.60^{b}±0.020	0.52^{c}±0.021	0.38^{d}±0.019	<0.01	<0.01	0.98
	%	2.8^{ab}±0.083	2.6^{a}±0.074	2.9^{bc}±0.083	3.0^{c}±0.076	<0.01	0.788	0.131
Dorsal trunk	kg	4.19^{a}±0.135	3.61^{b}±0.124	2.97^{c}±0.135	2.56^{d}±0.121	<0.001	<0.001	0.456
	%	16.8^{b}±0.416	18.2^{a}±0.381	16.0^{b}±0.416	18.0^{a}±0.371	0.137	<0.001	0.463
Ventral trunk	kg	2.03^{a}±0.073	1.91^{a}±0.067	1.63^{b}±0.073	1.38^{c}±0.065	<0.001	<0.01	0.325
	%	7.8^{c}±0.257	9.6^{a}±0.235	8.7^{b}±0.257	9.7^{a}±0.229	0.082	<0.001	0.27
Hind leg	kg	8.23^{a}±0.241	7.49^{b}±0.196	6.28^{c}±0.241	5.23^{d}±0.191	<0.001	<0.001	0.403
	%	32.8^{b}±0.680	37.7^{a}±4.662	33.8^{b}±0.680	36.7^{a}±0.607	0.974	<0.001	0.083
Back shank	kg	0.94^{a}±0.028	0.89^{a}±0.025	0.68^{b}±0.028	0.56^{c}±0.025	<0.001	<0.01	0.147
	%	3.5^{b}±0.525	4.3^{a}±0.480	3.4^{b}±0.525	4.7^{b}±0.468	0.787	0.036	0.650

[2] Percentage is calculated as a percentage of the cold carcass weight
[a-d] Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups.

Table 4.3: The effect of subspecies (Damara vs Karoo) and sex on the primal tissue composition (Least square means ± SE)

			Damara		Karoo		P-value		
Primal	**Tissue**		**Male N=10**	**Female N=10**	**Male N=10**	**Female N=10**	**Sub species**	**Sex**	**Sub X Sex**
Neck	**Meat**	%	80.3^{a}±4.693	60.2^{bc}±4.300	65.8^{b}±4.693	53.3^{c}±4.188	0.011	<0.001	0.344
	Bone	%	19.8^{b}±1.893	28.7^{a}±1.732	20.2^{b}±1.893	29.4^{a}±1.689	0.754	<0.001	0.918
	Waste	%	1.2^{b}±4.109	10.6^{a}±3.761	10.5^{a}±4.109	17.3^{a}±3.667	<0.01	0.013	0.536
Shoulder	**Meat**	%	78.0±1.278	73.2±1.170	77.5±1.278	69.1±1.140	0.040	<0.001	0.100
	Bone	%	18.7^{a}±0.659	19.0^{a}±0.603	17.9^{b}±0.659	22.3^{a}±0.588	0.061	<0.001	<0.001
	Fat	%	2.3^{b}±0.786	6.8^{a}±0.719	1.5^{b}±0.786	5.1^{a}±0.701	0.060	<0.001	0.521
Front shank	**Meat**	%	56.8±3.043	56.6±2.785	58.8±3.043	62.9±2.715	0.112	0.476	0.406
	Bone	%	38.6^{a}±3.546	32.7^{a}±3.246	36.0^{a}±3.546	41.0^{a}±3.164	0.344	0.889	0.075
Dorsal trunk	**Meat**	%	75.0^{a}±3.483	74.7^{a}±3.188	78.7^{a}±3.483	77.2^{a}±3.107	0.299	0.781	0.833
	Bone	%	18.5^{a}±1.147	17.1^{a}±1.050	18.0^{a}±1.147	17.3^{a}±1.023	0.843	0.327	0.695
	Fat	%	0.4^{c}±0.758	5.3^{a}±0.694	0.9^{b}±0.758	3.4^{c}±0.677	0.272	<0.001	0.061
Ventral trunk	**Meat**	%	77.8^{a}±1.553	78.2^{a}±1.420	79.7^{a}±1.553	78.4^{a}±1.430	0.438	0.741	0.533
	Bone	%	21.3^{a}±0.937	19.8^{ab}±0.857	20.5^{ab}±0.937	18.5^{b}±0.836	0.182	0.039	0.779
	Fat	%	0.0^{b}±0.445	1.2^{a}±0.408	0.2^{b}±0.445	0.6^{ab}±0.398	0.265	0.018	0.568
Hind leg	**Meat**	%	81.7^{a}±1.781	81.3^{a}±1.630	83.7^{a}±1.781	83.8^{a}±1.589	0.143	0.914	0.865
	Bone	%	14.5^{b}±0.488	14.3^{b}±0.447	14.3^{b}±0.488	15.8^{a}±0.436	0.125	0.124	0.044
	Fat	%	1.4^{bc}±0.447	2.8^{a}±0.409	1.0^{c}±0.447	2.4^{ab}±0.399	0.322	<0.01	0.901
Back shin	**Meat**	%	53.5^{a}±3.906	48.3^{a}±3.575	51.8^{a}±3.906	49.9^{a}±3.485	0.999	0.308	0.614
	Bone	%	40.9^{a}±2.330	42.1^{a}±2.133	43.0^{a}±2.330	39.1^{a}±2.079	0.840	0.511	0.210

Percentage is calculated as a percentage of the primal weight

$^{a-c}$ Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups.

Table 4.4: The effect of subspecies (Damara vs Karoo) and sex on the muscle yield (%) of springbok (Least square means ± SE)

		Damara		Karoo		P-value		
Muscle		**Male N=10**	**Female N=10**	**Male N=10**	**Female N=10**	**Sub species**	**Sex**	**Sub X Sex**
LTL*	%	44.0^{a}±2.091	45.8^{a}±1.914	44.4^{a}±2.091	43.4^{a}±1.865	0.560	0.835	0.422
BF	%	15.7^{b}±0.379	16.4^{a}b±0.389	15.8^{b}±0.425	17.2^{a}±0.379	0.226	0.012	0.368
SM	%	18.7^{b}±0.374	18.7^{b}±0.342	18.6^{b}±0.374	19.7^{a}±0.333	0.136	0.103	0.116
ST	%	5.1^{a}±0.122	4.8^{b}±0.112	5.4^{a}±0.122	5.3^{a}±0.109	<0.001	0.070	0.161
IS	%	5.5^{b}±0.268	6.5^{a}±0.308	5.1^{b}±0.147	6.5^{a}±0.271	0.719	<0.001	0.563
SS	%	4.9^{b}±0.177	6.5^{a}±0.222	5.1^{b}±0.138	6.1^{a}±0.133	0.870	<0.001	0.137

Percentage is calculated as a percentage of the primal weight
$^{a-d}$ Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups.
* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST), *Infraspinatus* (IS) and *Supraspinatus* (SS) muscles

4.3.2 Intensity of culling comparison (Trial 2)

The effect of intensity of harvesting and sex on carcass yields are presented in Table 4.5. There were significant interactions for both the dead and cold carcass weights, where the Wellington males had a heavier dead and cold carcass weight than the Wellington females. In contrast the Witsand males and females had similar dead weights and cold carcass weights. Meat yields differed for intensity of culling (P < 0.01) where the Wellington (low intensity) males had the highest meat yield, whereas the Witsand (high intensity) males and Witsand females had the lowest meat yields. The fat percentage differed between males and females (P < 0.01), where females had higher fat percentages than males.

Table 4.5: The effect of intensity of culling on the carcass yield and tissue proportions for male and female Karoo springbok (Least square means ±SE)

		Wellington (low intensity)		Witsand (high intensity)		P-value		
Carcass yield		**Male N=10**	**Female N=10**	**Male N=10**	**Female N=10**	**Cull**	**Sex**	**Cull X Sex**
Dead weight	kg	32.11^{a}±1.091	26.68^{b}±1.061	25.10^{b}±1.230	24.47^{b}±1.202	<0.01	<0.01	0.028
Cold carcass	kg	18.27^{a}±0.676	14.24^{b}±0.658	15.58^{b}±0.763	14.41^{b}±0.746	0.132	<0.001	0.034
Dressing	%[1]	56.9^{b}±1.138	53.6^{c}±0.1.107	61.9^{a}±1.284	58.84^{b}±1.255	<0.001	<0.01	0.919
Meat	kg	14.44^{a}±0.539	10.19^{b}±0.574	10.5^{b}±0.623	10.21^{b}±0.574	<0.01	<0.001	<0.001
	%[2]	77.8^{a}±1.430	73.7^{ab}±1.521	70.5^{b}±1.652	72.1^{b}±1.521	0.013	0.378	0.052
Bone	kg	3.42^{a}±0.112	2.85^{b}±0.120	2.85^{b}±0.130	2.81^{b}±0.120	0.027	<0.01	0.024
	%[2]	18.5±0.773	20.5±0.823	19.1±0.894	19.9±0.822	0.990	0.076	0.450
Fat	kg	0.20^{ab}±0.146	0.40^{a}±0.155	0.00^{b}±0.168	0.55^{a}±0.155	0.894	0.014	0.237
	%[2]	1.1^{bc}±0.855	2.85^{ab}±0.909	0.09^{c}±0.988	3.6^{a}±0.909	0.889	<0.01	0.288

[1]Percentage calculated as the proportion of the dead weight
[2] Percentage calculated as the proportion of the cold carcass weight
$^{a-d}$ Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups

The effect of intensity of culling and sex on the weight (kg) and percentage contribution to cold carcass weight of seven primals are presented in Table 4.6, where there were interactions between intensity of culling and sex for the neck percentage ($P = 0.035$) and the shoulder percentage ($P=0.042$). The wellington males and female springbok had similar neck and shoulder percentages, whereas the Witsand male and female springbok differed for the primal percentage. The Wellington and Witsand males had the highest primal percentage and the Witsand females the lowest. The Wellington males had a higher shoulder primal percentage than the Wellington females. In contrast the Witsand males and females had similar shoulder primal weights and primal percentages. The Wellington males also had the highest shoulder primal percentage contribution to the cold carcass weight. The percentage that the dorsal trunk contributed to the cold carcass weight had a significant sex effect ($P < 0.001$) where the dorsal trunk portion contribution was higher in females than in males. The Wellington springbok had a higher ventral primal ($P < 0.001$) percentage contribution to the cold carcass weight in comparison to the Witsand springbok. Female springbok ($P < 0.001$) also had a higher ventral trunk percentage contribution to the cold carcass weight in comparison to males. Female springbok had a higher hind leg ($P < 0.001$) percentage than their male counterparts.

Table 4.6: The effect of intensity of culling on the primal weight (kg) and yield (%) of male and female Karoo springbok (Least square means±SE)

		Wellington (low intensity)		Witsand (high intensity)		P-value		
Primal		Male N=10	Female N=10	Male N=10	Female N=10	Cull	Sex	Cull X Sex
Neck	kg	1.79^a±0.086	0.78^c±0.078	1.22^b±0.098	0.80^c±0.090	0.013	<0.001	<0.01
	%	9.5^a±0.366	5.6^b±0.334	8.1^a±0.418	5.8^b±0.381	0.167	<0.001	0.035
Shoulder	kg	4.63^a±0.187	3.22^b±0.182	3.54^b±0.211	3.20^b±0.207	0.020	<0.001	<0.01
	%	25.3^a±0.549	22.6^b±0.534	22.7^b±0.619	22.2^b±0.605	0.034	<0.01	0.042
Front shank	kg	0.51^a±0.019	0.38^b±0.018	0.44^b±0.023	0.40^b±0.021	<0.01	<0.01	0.980
	%	2.8±0.079	2.7±0.077	2.9±0.096	2.8±0.087	0.328	0.097	0.924
Dorsal trunk	kg	2.88±0.134	2.58±0.131	2.49±0.152	2.68±0.148	0.379	0.658	0.065
	%	15.8^b±0.466	18.0^a±0.454	16.1^b±0.526	18.6^a±0.514	0.437	<0.001	0.793
Ventral trunk	kg	1.68^a±0.059	1.37^b±0.058	0.65^c±0.067	0.77^c±0.065	<0.001	0.104	<0.001
	%	9.12^a±0.212	9.6^a±0.206	4.4^c±0.239	5.5^b±0.234	<0.001	<0.001	0.117
Hind leg	kg	6.18^a±0.200	5.40^b±0.195	5.05^b±0.226	5.22^b±0.221	0.011	0.117	0.018
	%	33.9^b±0.600	37.8^a±0.583	32.9^b±677	36.5^a±0.661	0.108	<0.001	0.834
Back shank	kg	0.68^a±0.024	0.56^b±0.023	0.59^b±0.027	0.55^b±0.026	0.115	<0.01	0.786
	%	3.7±0.123	3.9±0.120	3.9±0.139	3.9±0.136	0.799	0.412	0.487

[2] Percentage is calculated as a percentage of the cold carcass weight

[a-c] Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups.

The effect of intensity of culling and sex on the tissue composition (%) of the seven primal's are presented in Table 4.8. The Wellington males had significantly lower bone percentage in the neck, shoulder and ventral trunk when compared to the Witsand males. In contrast the Wellington females and Witsand females had similar bone percentages. The Wellington males also had a significantly higher meat percentage in the shoulder than the Wellington males, whereas females of both farms once again did not differ for the meat percentage of the shoulder. Female springbok had a higher bone percentage in the neck (P < 0.01) and shoulder (P < 0.01). Female springbok also had a higher fat percentage than male springbok in the shoulder (P < 0.001), dorsal trunk (P < 0.001) and hind leg (P < 0.01). Male springbok had a higher meat percentage in the hind leg (P < 0.01).

Table 4.7: The effect of intensity of culling on the meat, bone and fat percentage of the main primals per male and female Karoo springbok (Least square means±SE)

			Wellington (low intensity)		Witsand (high intensity)		P-value		
Primal	**Tissue**		**Male N=10**	**Female N=10**	**Male N=10**	**Female N=10**	**Cull**	**Sex**	**Cull X Sex**
Neck	**Meat**	%	60.1±4.643	54.5±4.231	54.9±5.297	47.5±4.830	0.289	0.141	0.839
	Bone	%	19.9^{b}±2.042	30.1^{a}±1.861	26.33^{c}±2.330	34.01^{b}±2.125	0.044	<0.001	0.510
	Waste	%	13.4±4.277	15.4±3.897	19.7±4.879	17.7±4.449	0.411	0.996	0.620
Shoulder	**Meat**	%	77.0^{a}±3.688	69.7^{ab}±3.588	65.9^{b}±4.161	70.6^{ab}±4.066	0.179	0.525	0.054
	Bone	%	18.1^{a}±1.022	22.4^{b}±0.995	19.2^{b}±0.995	21.1^{ab}±1.127	0.934	<0.01	0.228
	Fat	%	1.4^{b}±0.409	1.7^{a}±0.398	0.8^{b}±462	0.39^{a}±0.451	0.712	<0.001	0.391
Front shank	**Meat**	%	61.3±3.677	64.0±3.558	64.6±4.451	59.5±4.052	0.11	0.48	0.41
	Bone	%	35.4±2.634	41.1±2.549	38.8±3.189	37.3±2.903	0.34	0.89	0.08
Dorsal trunk	**Meat**	%	80.6^{a}±3.273	78.1^{a}±3.185	81.6^{a}±3.693	78.3^{a}±3.609	0.887	0..359	0.905
	Bone	%	17.7^{a}±1.113	16.8^{a}±1.083	18.0^{a}±1.256	18.8^{a}±1.227	0.394	0.977	0.437
	Fat	%	1.6^{bc}±0.901	3.6^{ab}±0.876	0.4^{c}±1.016	4.7^{a}±0.993	0.671	<0.001	0.079
Ventral trunk	**Meat**	%	76.3±3.900	76.9±3.929	69.7±4.399	69.0±4.299	0.138	0.984	0.857
	Bone	%	20.0^{b}±1.392	18.7^{b}±1.354	34.0^{a}±1.570	32.0^{a}±1.535	<0.001	0.225	0.790
	Fat	%	0.5^{b}±2.046	2.1^{ab}±1.991	1.5^{b}±2.308	1.3^{a}±2.256	0.350	0.016	0.087
Hind leg	**Meat**	%	83.8^{ab}±1.028	80.7^{c}±1.000	84.2^{a}±1.159	80.7^{bc}±1.133	0.876	<0.01	0.869
	Bone	%	14.2±0.526	15.2±0.512	15.0±0.594	13.8±0.580	0.642	0.949	0.037
	Fat	%	1.2^{ab}±0.600	2.6^{a}±0.584	0.8^{b}±0.677	2.9^{a}±0.662	0.980	<0.01	0.544
Back shin	**Meat**	%	51.8^{ab}±1.562	48.0^{b}±1.520	54.2^{a}±1.762	51.5^{ab}±1.722	0.129	0.037	0.730
	Bone	%	41.5±1.873	38.7±1.823	41.2±2.113	43.0±2.065	0.376	0.777	0.211

Percentage is calculated as a percentage of the primal weight

$^{a-c}$ Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups.

The effect of intensity of culling and sex on the muscle yields are presented in Table 4.8, where there were interactions between intensity of culling and sex for the IS percentage (P<0.01). The Wellington female springbok had a higher IS percentage than their male counterparts, whereas the Witsand male and female springbok had a similar IS percentage. The LTL muscle did not differ between subspecies nor between sexes. The Witsand springbok had a higher percentage SM (P<0.01), whereas the Wellington springbok had a higher percentage ST (P=0.04). Male springbok had a higher percentage ST (P<0.01), whereas female springbok had a higher percentage SS (P<0.001).

Table 4.8: The effect of intensity of culling on the muscle yields (%) of male and female Karoo springbok (Least square means ±SE)

		Wellington (low intensity)		Witsand (high intensity)		P-value		
Muscle		**Male N=10**	**Female N=10**	**Male N=10**	**Female N=10**	**Cull**	**Sex**	**Cull X Sex**
LTL	kg	1.27±0.066	1.12±0.064	1.21±0.074	1.19±0.072	0.97	0.19	0.28
	%	44.5^{a}±1.768	43.8^{a}±1.720	48.1^{a}±1.994	44.7^{a}±1.949	0.307	0.237	0.428
BF	kg	0.98^{a}±0.037	0.90^{ab}±0.036	0.82^{b}±0.042	0.85^{b}±0.041	0.02	0.48	0.11
	%	15.9^{b}±0.235	16.6^{a}±0.228	16.1^{ab}±0.265	16.2^{ab}±0.259	0.772	0.063	0.143
SM	kg	1.13±0.049	1.02±0.048	1.12±0.056	1.02±0.054	0.92	0.04	0.96
	%	18.1^{b}±0.576	18.9^{b}±0.560	21.9^{a}±0.650	19.5^{b}±0.635	<0.01	0.133	<0.01
ST	kg	0.34^{a}±0.013	0.28^{b}±0.013	0.27^{b}±0.015	0.26^{b}±0.015	0.01	0.02	0.05
	%	5.5^{a}±0.084	5.2^{bc}±0.082	5.2^{ab}±0.095	5.0^{c}±0.093	0.039	<0.01	0.950
IS	kg	0.24^{a}±0.014	0.20^{a}±0.013	0.23^{a}±0.016	0.20^{a}±0.015	0.65	0.02	0.94
	%	5.0^{b}±0.259	6.4^{a}±0.247	6.5^{a}±0.286	6.1^{a}±0.280	0.047	0.058	<0.01
SS	kg	0.24^{a}±0.008	0.19^{b}±0.008	0.18^{b}±0.009	0.19^{b}±0.009	0.01	0.03	<0.01
	%	5.1^{b}±0.206	6.0^{a}±0.200	5.3^{b}±0.232	6.1^{a}±0.227	0.588	<0.001	0.715

Percentage is calculated as a percentage of the primal weight

$^{a-c}$ Superscripts within the same row with different letters, differ significantly (p≤0.05) between treatment groups.

* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST), *Infraspinatus* (IS) and *Supraspinatus* (SS) muscles

4.5 DISCUSSION

4.5.1 Subspecies comparison (Trial 1)

There was a significant difference in dead weight and carcass weight between Damara and Karoo springbok, as discussed in Chapter 3. This size difference could have financial implications as larger springbok have a lower cost to the rancher per kilogram. It has yet to be determined if subspecies also differ for the primal percentage contribution to the cold carcass weight (neck, forelimb, ventral trunk, dorsal trunk and back leg). Thus, this study aimed to determine whether there was any potential financial gain for one subspecies above the other.

The Damara springbok had heavier meat and bone weights as could be expected due to their larger size and subsequently weight. But the Damara and Karoo springbok did not differ in terms of meat-, bone- or fat percentage of the total carcass (Table 4.1). Springbok carcass comprised of 73.8-77.9% meat, 19.0 – 20.4% bone and 0.9 – 3.4% fat. This indicated that springbok from both subspecies were of comparable meat production potential. Game species have been noted to have a lesser extent of fat in comparison to domestic species and thus have similar compositions. This is illustrated in the comparability of springbok to various other game and venison species such as Rusa deer (Dahlan, 2009), impala, red deer and fallow deer (Kudrnáčová, Bartoň, Bureš, & Hoffman, 2018). Although it should be considered that the carcass composition of venison has been noted to vary between seasons, especially for male animals (Wiklund, Finstad, & Bechtel, 2005), thus making comparisons across studies challenging as studies differed in terms of age, sex and season, all of which affects the carcass composition (Drew & Hogg, 1986; Wiklund et al., 2005). This is illustrated in the comparable carcass composition of springbok and fallow deer as reported by Wiklund et al., (2005). In contrast Drew & Hogg, (1986), reported higher fat and lower lean meat percentage and Fitzhenry et al., (2019) reported higher bone and lower lean meat percentages for fallow deer. The difference in ages, region and season complicate accurate comparison. Sex is also a notable factor that affects the carcass composition, where females have been reported to have a higher fat percentage in comparison to females. This was seen in the higher fat percentage of female springbok in comparison to male springbok (Table 4.1)

The Damara subspecies had heavier (kg) primal weights than the Karoo subspecies. These differences can be attributed to the heavier dead weights and cold carcass weights of the Damara subspecies (Table 4.1). The percentage contribution of each primal portion to the cold carcass weight except for the forelimb (Table 4.2) and neck (Table 4.2), were similar between the Damara and Karoo subspecies. The Damara males also had a lower percentage ventral trunk than the Karoo males. The higher Damara males' forelimb percentage contribution to the cold carcass weight was significantly higher than the Karoo males and females.

Dahlan, (2009) suggested that male rusa deer, as is common in a variety of mammals, had a larger forequarter and neck, as these are dominant male traits. It has also been reported that male dominant traits such as neck size have an increased growth rate in comparison to less dominant traits (Von la Chevallerie & Van zyl, 1971) .Thus, if this trend were to persist then older male animals would have a proportionally higher neck percentage than younger animals. In fact the neck in red deer increased proportionally between the ages of 1 year and 9 years and the neck of fallow deer also showed a tendency towards increasing in proportion between one and two year old stags (Drew & Hogg, 1986). Volpelli *et al*, (2002) also found that neck percentage increased in the older stags when comparing 18-month-old stags to 30-month-old stags. Although the shoulder portion in fallow deer was reported to decrease between 1 year and 2-year-old stags (Drew & Hogg, 1986) as well as between 18-month-old and 30 month old fallow deer stags (Volpelli et al., 2002; Żochowska-Kujawska, Kotowicz, Sobczak, Lachowicz, & Wójcik, 2019). In contradiction to this trend 30 and 42-month-old fallow deer stags did not differ in terms of shoulder weight (Żochowska-Kujawska et al., 2019). In red deer a decrease in the shoulder proportional percentage between 1, 2 and 9-year-old stags was (Drew & Hogg, 1986). The challenge in springbok is that there are no studies as of yet that show the effect of accurately determined ages on the proportional development within the carcass nor any data on the differences in carcass proportions throughout their growth. Drew & Hogg, (1986), reported that the ribs of red deer and fallow deer decreased proportionally as the animals aged, whereas the New Zealand wapiti and a hybrid of red deer and wapiti showed an increase in the ribs proportionally as the animal aged. This suggests that changes in the proportional carcass could be species or dissection specific.

The neck's meat percentage of Damara males was significantly higher than Karoo male's meat. The waste portion was characterised as meat not fit for human consumption, and in the neck primal this was most often meat that had bone shards. The significant difference between Damara males and Karoo male's neck meat percentage can be partly attributed to the differences in waste where Damara males had a much lower waste. The Karoo males had a larger occurrence of high neck shots whilst the Damara males were all shot in the head and thus the former increased the waste percentage of the Karoo males. Thus, the true subspecies differences for the neck's yield are somewhat obscured by the vast variation in neck damage and thus, in waste between trials (subspecies).

The dorsal trunk is an economically significant primal as it is primarily made up of the expensive LTL muscle. Subspecies did not have different meat and bone percentages (Table 4.4). The LTL muscle percentage ranged between 44 – 46%, this is similar to Von la

Chevallerie *et al*., (1971) in which it was noted that springbok had very well-developed loins. This phenomenon is possibly due to the pronk enabling function of the LTL muscle.

Male and female animals frequently have different growth rates in different body regions. These different growth rates result in male and female animals, frequently having different proportional compositions (Lawrie & Ledward, 2006). For the most part, these different growth rates are attributed to differences in sex hormones. However, it has been noted that young female springbok can have a slower growth rate due to the added nutritional strain of a foetus (Von la Chevallerie & Van Zyl, 1971). There were differences in proportional body composition in the current study where male and female springbok differed for the neck (Table 4.3), shoulder (Table 4.3), dorsal trunk, ventral trunk (Table 4.3) and back leg (Table 4.3) percentage contribution to the cold carcass weight.

Mature springbok males have significantly larger necks than females; typical of sexual dimorphism (Table 4.2). The rate of neck growth in mature male springbok is higher than in female springbok, thus resulting in a heavier neck in males at comparable ages (Von la Chevallerie & Van Zyl, 1971). Similarly, male impala also have larger necks than female impala, and their weight (kg) and contribution (%) to cold carcass were higher than their female counterparts (Hoffman, 2000). In contrast, fallow deer males had heavier necks than females but not higher percentage contributions to cold carcass weights (Fitzhenry *et al*., 2019).

Males had a higher percentage proportion of the forelimb and females had a higher percentage proportion of the dorsal trunk, ventral trunk and back leg. These differences were consistent with the reported differences in impala (Hoffman, 2000), where males had a higher percentage of forequarter and females had a higher percentage hind leg. This is also consistent with reports in which male animals have a larger forequarter as it is a dominant male characteristic that is commonly recorded in ruminants (Dahlan, 2009).The sex differences were, however, not reported in all species/breeds; this is illustrated by the lack of sex differences between primal percentage proportions in fallow deer (Stanisz *et al*., 2015) and Namibian springbok (*Antidoras marsupialis hofmeyri*) (Van Schalkwyk, 2019). It should be considered that the Namibian springbok were younger than the springbok in the current study and age influences the proportional composition of animals (Volpelli et al., 2002).

Male and female animals mature at different rates and have different growth rates of the various tissues (meat, bone and fat) (Moloney & McGee, 2017). However, these differences would seem to be species/breed specific. Male springbok had higher meat percentages for the neck (Table 4.2) and forelimb (Table 4.3). Female animals tend to accumulate a higher level of fat to assist them in times of increased stress, such as lactation (Young, 1976). Thus, females have an increased fat percentage and so have a lower meat percentage in comparison to males (Fourie, Kirton, & Jury, 1970). This was illustrated in the current study where the total lean meat percentage was higher in males than in females, due to female springbok having a higher fat percentage than male springbok. The carcass composition of springbok suggests that springbok are highly favourable for lean meat production, independent of subspecies or sex.

4.5.2 Intensity of culling comparison (Trial 2)

Selective culling, as previously discussed in Chapter 3, is caused by trophy hunting and culling of larger males. This decreased the number of larger males within a population before they have adequate time to breed. Larger males generally sire a higher number of offspring than smaller males. In springbok, breeding males are solitary and territorial (Skinner & Louw, 1996). Decreasing these breeding males means that smaller males sire more offspring than they normally would in an undisturbed population. Over time this leads to a decrease in dead weight and horn size of the males within a population (Festa-Bianchet, Pelletier, Jorgenson, Feder, & Hubbs, 2014). This decrease in deadweight is discussed in Chapter 3. No research has been done on the influence of high intensity of culling on the carcass weights of any species. Nor has any research been conducted on whether the increased intensity of culling would influence the primal composition of any species. This study aimed to determine whether a high intensity of culling in which males were specifically selected would influence the yield and percentage contribution of any primal (neck, front limb, ventral trunk, dorsal trunk and back limb). The study further aimed to determine if this increased intensity of culling would influence any primal's composition (meat, bone, fat, waste).

The difference in males' size that were illustrated in Chapter 3 is further seen in the differences between males from the Wellington farm (low intensity culling) and the Witsand farm (high intensity culling). The Wellington males had higher percentage contribution to cold carcass weight for the shoulder and ventral trunk (Table 4.6). Females between the farms did not differ for any primal weights nor primal's contribution to cold carcass weight. Differences between males were also observed within the composition of the ventral trunk and shoulder. Where Wellington males had a higher meat and lower bone percentage than the Witsand males, this increased bone percentage could indicate a decrease in the muscularity of the Witsand males. As the larger males are hunted, the smaller males are left behind as the breeding males, this inadvertently causes a decline in the size of males, and male-female differences are no longer significant. This decline in size is similar to what happens in goats when fast-growing young males are sold at a young age, and the slower-growing males are left in the herd to breed (Simela, Ndlovu, & Sibanda, 1999).

It has been reported that when there is a high level of selective culling of males within a population, the average age of the male population tends to decrease as the larger older males are culled first (Douhard, Festa-Bianchet, Pelletier, Gaillard, & Bonenfant, 2016; Festa-Bianchet et al., 2014).The effect of age thus also has to be taken into account. After 12 months, springbok are classed as adult. In most studies conducted on springbok that have either studied age or taken ages into account, springbok have been classed as either adult or sub-adult (Hoffman, van Schalkwyk, & McMillin, 2019; Kroucamp, 2004; Van Zyl & Ferreira, 2004). The determination of adult has ranged between 12 months (Hoffman et al., 2019) and 24 months (Kroucamp, 2004). No studies have reported the weight, dressing percentage or proportional composition differences between male and female springbok at different set age intervals within the adult age group. The proportional composition of animal changes as it grows and an animal increases in weight throughout its life, provided that it has access to sufficient food The proportion of bone is known to decrease in an animal's body as it grows (Black, 1988), due to the increase in muscle and later fat growth of an animal (Berg, 1968a, 1968b). Thus, a younger animal has a higher proportion of bone and a lower proportion of muscle than an older animal (Berg, 1968a, 1968b; Black, 1988). Wellington males only had a lower proportion of bone in the neck, shoulder and ventral trunk in comparison to Witsand males (Table 4.7). The total bone of the carcass did not differ between the Wellington and Witsand farm. Thus, although the Witsand animals were of equal maturity in terms of tissue proportions, the Witsand males were still much smaller than the Wellington males. The Witsand males had similar proportions and weights as the Witsand females, whereas the Wellington males and females had similar tissue proportions (except fat), but Wellington males had heavier primal weights in comparison to Wellington females.

Males and females do not necessarily have the same growth rates of tissues and so can differ for proportional tissue (muscle, bone and fat) (Lawrie & Ledward, 2006). Differences in primal percentage between males and females were observed on the Wellington and Witsand farm for the neck, dorsal trunk and hind leg. The Wellington farm's males had a higher forelimb percentage than females. This did not occur on the Witsand farm. This could be due to a decreased muscularity in Witsand males' forelimb (due to the males being younger) as the forelimb is considered a dominant trait that manifests in sexually mature males (Dahlan, 2009).

The LTL is an economically important muscle and contribute between 42.6 to 46 % of the dorsal trunk cut. Interestingly the LTL did not differ in weight or percentage contribution between the Wellington farm and Witsand farm. There were also no differences between males and females for the LTL weight. This could be related to the importance of the function of the LTL. The LTL in springbok plays an essential role in the animal's ability to pronk and is utilised to such an equal extent by all springbok. Also, the growth curves described by earlier researchers such as Berg (1968a, 1968b) all ended with the growth rates moving from the extremities through the dorsal back and ending in the belly region of old animals. It is postulated that the springbok in these Trials were all still growing and had reached the stage where the growth rate of the back was equal to 1 (relative to the incease in body weight), but not old enough for the growth rate of the belly to be >1.

4.5 CONCLUSION

Damara and Karoo springbok have significant differences in size (Chapter 3). There also exist significant differences between Damara and Karoo springbok for each primal weight. However, the two subspecies do not differ in terms of composition. For the most part, each primal has a constant contribution to the cold carcass weight independent of subspecies. The Karoo subspecies is a smaller subspecies, but they have the same proportions as the Damara springbok. Damara springbok thus have a lower cost/kg ratio as the cost to cull a single animal is constant independent of that animal's weight. At a constant price per kilogram, the Damara subspecies will have a lower cost per kilogram and thus a higher profit per kilogram.

The male springbok from the Wellington farm had a heavier neck, front limb, ventral trunk and back limb weight. Only the dorsal trunk showed no difference between the males from each farm. There were few differences in terms of percentage of each primal portion. Female springbok did not differ between the two farms. There was evident sexual dimorphism on the Wellington farm for both absolute weights and percentages. In contrast, the Witsand farm had fewer differences between males and females and most differences were in terms of proportions. The Wellington males and Witsand males had similar tissue proportions but the Wellington males had heavier primal weights than the Witsand males. These differences could be linked to the Wellington springbok being older and thus showing more sexual dimorphism, especially as pertaining to the male animals. High intensity of harvesting in which large males are selectively harvested seems to mostly affect the size of the male population.

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CHAPTER 5

PHYSICAL MEAT QUALITY CHARACTERISTICS OF SPRINGBOK (*ANTIDORCAS MARSUPIALIS)* AS INFLUENCED BY SUBSPECIES, SEX, AND INTENSITY OF CULLING.

ABSTRACT

This study aimed to determine the influence of subspecies (Damara and Karoo), sex, and intensity of culling on the physical meat quality characteristics of springbok. The pH_u did not differ between subspecies, sex, or farms (intensity of culling) and fell within the acceptable range (5.3-5.7). Cooking loss %, drip loss %, and shear force (N) were all higher in the Damara subspecies, and males also had higher cooking loss %, drip loss %, and shear force than females. The shear force values for both the Damara and Karoo subspecies were below 33N, and so both subspecies' meat can be classified as tender. The Karoo subspecies had higher L*, a*, b*, and chroma values in comparison to the Damara subspecies making the Karoo meat lighter, redder, and more vivid (saturated). Physical meat quality differences between subspecies were not necessarily large enough for one subspecies to be beneficial over the other in terms of physical meat quality. The intensity of culling trial yielded few differences between Wellington (low intensity) and Witsand (high intensity) springbok for pH_u, cooking loss%, drip loss%, shear force, and colour. Thus, the high intensity of culling did not influence the physical meat quality characteristics of springbok when enough time has progressed between culls, and springbok had time to replenish their glycogen reserves.

Keywords: Subspecies, sex, physical meat quality, intensity of culling

5.1 INTRODUCTION

Consumer-driven preferences can be a shaping force behind agriculture (Issanchou, 1996; Lund & Jensen, 2012). Meat consumption is often used as an indicator of economic growth or economic well-being (Bereżnicka & Pawlonka, 2018). Thus, when there is economic growth, meat consumption tends to increase. The consumers' purchase intent has changed from purely buying based on the price to buying based on the price as well as non-economic factors such as health and convenience (Taljaard, Jooste, & Asfaha, 2006). Very wealthy consumers have a decreased consumption of meat due to health-related concerns and safety concerns (Bereżnicka & Pawlonka, 2018). The meat that they do purchase is greatly influenced by meat quality characteristics (Udomkun *et al.*, 2018). Most consumers prefer meat with less visible fat (Ngapo, Braña Varela, & Rubio Lozano, 2017) as it is perceived to be healthier. Studies have noted that men prefer red meat in comparison to women that prefer white meat; this again is thought to be because white meat has less visible fat, and women are more health-conscious (Kubberød, Ueland, Rødbotten, Westad, & Risvik, 2002). Game meat has very little fat in comparison to domestic species, and so can be very appealing to the more health-conscious consumer (Hoffman & Wiklund, 2006). The South African game industry is made up of four primary components, namely, trophy hunting, breeding, ecotourism, and processed products (Van der Merwe, Saayman, & Krugell, 2004). The meat production sector (processed products) is still very underdeveloped. Consumer's opinion on game meat is varied, and there are multiple challenges. These challenges include consistent supply, underdeveloped market, and the inconsistency of quality that is delivered (Wassenaar, Kempen, & van Eeden, 2019). It is, therefore, essential to consider the wide variety of factors that can influence the physical meat quality.

The physical meat quality of game meat is generally determined by considering colour, tenderness and water-holding capacity. The muscle glycogen levels at slaughter directly influence the colour, tenderness and water-holding capacity of meat (WHC) (Hood & Tarrant, 1982; Wiklund, Manley, & Littlejohn, 2004). *Post mortem* temperature, rate of pH decline and ultimate pH plays a significant role in the determination of meat tenderness, colour and WHC (Wiklund *et al.*, 2004; Yu & Lee, 1986). Ultimate pH, in turn, is influenced by factors such as season (Wiklund, Dobbie, Stuart, & Littlejohn, 2010), sex and *ante mortem* stress (Lawrie, 2010). Diet can also influence the level of glycogen at slaughter and so influence the ultimate pH and meat quality traits (Lawrie & Ledward, 2006). In choosing meat, consumers find tenderness, colour, and colour stability as the most crucial physical meat quality traits (Koohmaraie, 1995; Neethling *et al.*, 2017). Game/venison meat tenderness is also greatly influenced by species, age, sex, muscle type and *ante mortem* stress (Lawrie, 2010; Wiklund, Barnier, Smulders, Lundström, & Malmfors, 1997; Wiklund, Stevenson-Barry, Duncan, &

Littlejohn, 2001). A variety of extrinsic factors such as season and management and intrinsic factors such as species, muscle and myoglobin content influences the colour and colour stability of meat (Neethling, Sigge, Hoffman, & Suman, 2018; Neethling *et al*., 2017, 2016).

Springbok are ideal game species for meat production as they are abundant (Jooste, 2011), they have high dressing percentages (Van Zyl & Ferreira, 2004) and good eating quality (Hoffman, Kroucamp, & Manley, 2007b). Springbok has some of the most tender meat in comparison to most game species (Von la Chevallerie, 1972). Springbok is also the most popular game meat for export (SADAFF, 2010). There have been various studies quantifying a specific effect on the physical meat quality of springbok. These have included the effect of age and sex (Hoffman, van Schalkwyk, & McMillin, 2019; Van Zyl & Ferreira, 2004), production region (Hoffman, Kroucamp, & Manley, 2007a) and muscle type (North & Hoffman, 2017). Most studies conducted on springbok have been conducted on the Karoo subspecies, and minimal comparison between the two subspecies (Damara) has been made in terms of meat quality; research on Namibian springbok has only been on the Kalahari subspecies and not the Damara (Hoffman *et al*., 2019).

Studies on big horned sheep (Coltman *et al*., 2003; Festa-Bianchet, Pelletier, Jorgenson, Feder, & Hubbs, 2014; Hedrick, 2011), have noted a decrease in body size and horn size of males in populations that have experienced selective culling over time. This decline is due to the inadvertent directional selection against the characteristics/traits that are financially important (Harris, Wall, & Allendorf, 2002). The selective culling decreased the average age of the male population although the influence that high intensity of selective culling over a long period has on the physical meat quality has yet to be quantified. The aims of this study were first to determine whether there was a difference between Damara and Karoo subspecies for males and females in terms of physical meat quality (Trial 1). The second aim was to determine whether there was a difference in meat quality between the high (Witsand population) and low (Wellington population) intensity of culling for both male and female Karoo springbok (Trial 2).

5.3 MATERIALS AND METHODS

5.3.1 Animals and Study location

Sixty springbok were culled for two months on three different farms. Trial 1 (subspecies comparison) consisted of twenty Damara (*A. m. angolensis*) and twenty Karoo (*A. m. marsupialis*) springbok. Each subspecies consisted of ten mature male and ten mature female springbok. Trial 2 (Intensity of culling) consisted of twenty Karoo springbok from a farm near

Wellington (low intensity) and twenty Karoo springbok from a farm near Witsand (high intensity) - all mature. Ten male and ten female springbok were culled on each farm. Age of animals was determined by wear and tear of teeth (Dewar, Halkett, Hart, Orton, & Sealy, 2006). Damara and Karoo (Wellington) springbok were between 18 months and five years old. Karoo springbok from Witsand ranged in age between 12 month and 2 years old. A more detailed description of each farm is given in Chapter 3, section 3.2.1.

5.3.2 Culling and Dressing

Animals were harvested using the same procedure on each of the three farms. Headshots were used, and the animals were exsanguinated within two minutes of killing (Ethical Clearance Number: 10NP_HOF02). Headshots allowed for the least carcass damage and the least change in the biochemical mechanisms in the body that are associated with stress and influence meat quality. Headshots also decrease the occurrence of rumen fluid and blood contaminating the carcass (van Schalkwyk & Hoffman, 2016), as well as decreasing shot-related meat quality effects (Von La Chevallerie & Van Zyl, 1971). Although in the Karoo subspecies from Wellington farm, a high occurrence of high neck shots was reported in the field notes. These neck shots were caused by observations that these springbok were wild and had a long distance flight zone resulting in the marksmen having to shoot most animals at distances further than 200 m. Discussions with the manager of the farm indicated that this population had been hunted 20 years prior to this trial when all the animals that were close to the hunters had been killed; this may have resulted in an indirect selection against 'tameness'. Carcasses were transported back to the abattoir area, and the deadweight recorded, after which animals were eviscerated. A more detailed description of the evisceration can be found in Chapter 3, section 3.2.2. Following evisceration, carcasses were loaded into the chiller with a temperature of 4°C.

5.3.3 Sample preparation

Carcasses were removed after 24 hours from the chiller and divided in half, as described in Chapter 4. The left side of each carcass was used for the block test (Chapter 4), and the right side of the carcass was used to determine the physical meat quality of specific muscles. Three muscles from the hindquarter and one from the back were used. The following muscles were removed: *M. longissimus thoracis et lumborum* (LTL), *M. biceps femoris* (BF), *M. semimembranosus* (SM), and *M. semitendinosus* (ST). Firstly, the pH of each muscle was measured. Chemical analysis samples were then cut from each muscle (approx. 150g), and the remaining muscle was used for physical analysis.

5.3.4 Physical analyses

All the muscles were first removed from the carcass, and then pH was measured. The ultimate pH (pH_u) was measured approximately 24 hours *post mortem*, (when rigor had already resolved) in the centre of each muscle. pH was measured using a portable Crison pH 25 pH meter (Crison Instruments, Barcelona Spain) calibrated at pH 4 and pH 7 (two-point calibration). After each pH measurement, the glass electrode was cleaned with distilled water and blotted dry.

One 2 cm thick steak was used to determine cooking loss and colour. Each steak was placed on a solid white surface and allowed to bloom for 30 minutes at a temperature of approximately 10˚C. Five colour measurements were taken at random on the surface of the bloomed steak using a colour-guide 45°/0° calorimeter (BYK-Gardner GmbH, Gerestried, Germany; aperture diameter size: 11mm; observer angle: D-65/10˚). The CIE L*(lightness), CIE a* (green-red), and CIE b*(blue-yellow) convention was used to interpret colour. These values were then used to determine the hue angle (colour definition) and chroma (saturation) value using the formulas below:

$$\textit{Hue- angle } (h_{ab}) = \tan^{-1} \frac{b*}{a*} ,$$

$$\textit{Chroma } (C^*) = \sqrt{(a*)^2 + (b*)^2} .$$

After colour was measured, the steaks were weighed and placed in marked bags and cooked at 80°C for 45 minutes, after which they were removed, and fluid was drained from each bag. Steaks were then left to cool down in closed bags in a chiller at a temperature of 4°C overnight. The following day each steak was lightly blotted dry with a paper towel and weighed. Cooking loss percentage was determined using the initial pre-cooked weight and the post-cooking weight to determine the amount of moisture that would be lost in the cooking process.

$$Cooking\ loss\ \% = \frac{\text{Initial raw weight}(g) - Cooked\ weight(g)}{\text{Initial raw weight (g)}} \times 100$$

Drip loss determines the water holding capacity of each muscle. A 2 cm thick steak was used to determine drip loss percentage. The steak was weighed and then suspended in an inflated plastic bag taking care that the steak did not touch the bag. The bags were hung for 24 hours in a chiller at a temperature of 4°C where after the steak was removed and blotted dry with a paper towel and weighed. Moisture loss was determined by using the difference in weight as a proportion of the initial weight.

$$Drip\ loss\ \% = \frac{\text{Initial weight}(g) - after\ weight(g)}{\text{initial weight (g)}} \times 100$$

Shear force is a unit of measurement that is used to describe the tenderness of the meat and is an imitation of the biting action of the consumer. Samples used to determine cooking loss were used for the measurement of tenderness. Tenderness was determined using the Warner-Bratzler (WBS) shear force values determined on a mobile unit equipped with a Warner-Bratzler blade, 1.2 mm thick with a triangular cutting blade, 13 mm at the widest point and 15 mm high. After measuring cooking loss, six 1.27 cm diameter cylindrical core samples were removed parallel with the longitudinal axis (grain) of the fibres using a hand corer and sheared perpendicular to the grain of the muscle. Measurements were taken as the maximum shear force (kg/1.27 cm ø) at a crosshead speed of 33.3 mm/s. Shear force values were converted to newton (N) using the formula:

$$WBSF = (kg/1.27cm\ ø * 9.81)\ /\ Area,$$

$$where\ Area = \pi(\tfrac{1.27}{2})^2.$$

5.3.5 Statistical Analysis

Statistical analysis was done using the Statistica 64 version 13.4 (2018) VEPAC model. Trial 1 and 2 both consisted of a 2x2 factorial design experimental layout. Trial 1 had subspecies and sex as its main effects, and Trial 2 had intensity of culling and sex as main effects. A two-way ANOVA (univariate analysis of variance) was constructed for both Trial 1 and Trial 2, using the Mixed Model of STATISTICA per muscle, to determine significant differences between main effects and a significant interaction of main effects. Age was also included as a covariate. Levene's test was conducted to test for deviation from homoscedasticity, and a Shapiro-Wilk test was performed on the standardised residuals to test for the assumption of normality and determine whether outliers were present (Shapiro, Wilk, & Unwin, 2013).

5.4 RESULTS

5.4.1 Subspecies comparison (Trial 1)

The effect of subspecies (Damara vs Karoo) and sex on the pH_u of springbok are presented in Table 5.1, where there were no significant interactions between subspecies and sex for any of the four muscles (LTL, BF, SM, or ST). Also, neither subspecies nor sex influenced the pH_u of any of the muscles.

Table 5.1: The effect of subspecies (Damara vs Karoo) and sex on the ultimate pH (Least square means ± SE)

	Damara		Karoo		P-value		
pH_u	**Male n=10**	**Female n=10**	**Male n=10**	**Female n=10**	**Sub species**	**Sex**	**Sub X Sex**
LTL*	5.44±0.039	5.48±0.036	5.46±0.039	5.46±0.036	0.949	0.661	0.637
BF	5.46±0.056	5.46±0.051	5.49±0.056	5.48±0.051	0.558	0.906	0.855
SM	5.46±0.052	5.44±0.047	5.52±0.052	5.52±0.048	0.099	0.849	0.839
ST	5.52±0.058	5.49±0.053	5.52±0.058	5.48±0.053	0.882	0.451	0.978

* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

The effect of subspecies and sex on the drip loss percentage of muscles are presented in Table 5.2; where there were significant interactions between subspecies and sex for the drip loss percentage of the LTL and ST muscles. Subspecies (P<0.01) and sex (P<0.01) effects for the drip loss of the SM and BF were also found, where the Damara subspecies and females generally had a higher drip loss percentage.

Table 5.2 The effect of subspecies (Damara vs Karoo) and sex on the drip loss % and cooking loss % (Least square means ± SE)

	Damara		Karoo		P-value		
Drip Loss %	**Male n=10**	**Female n=10**	**Male n=10**	**Female n=10**	**Sub species**	**Sex**	**Sub X Sex**
LTL*	2.31^b±0.216	3.18^a±0.198	1.92^b±0.233	1.28^c±0.193	<0.001	0.556	**<0.001**
BF	2.21^b±0.241	2.88^a±0.196	1.25^c±0.231	1.22^c±0.191	**<0.001**	**0.108**	0.068
SM	2.40^b±0.216	3.40^a±0.197	1.53^c±0.232	1.80^c±0.193	**<0.001**	**<0.01**	0.057
ST	1.61^b±0.147	2.26^a±0.135	0.93^c±0.159	0.84^c±0.132	<0.001	0.039	**<0.01**
Cooking Loss %							
LTL	36.70^a±0.896	33.74^b±0.820	33.93^b±0.896	30.67^c±0.799	<0.001	<0.00	0.840
BF	39.44^a±0.670	36.88^b±0.599	36.27^{bc}±0.69	34.81^c±0.599	<0.001	<0.01	0.345
SM	38.8^a±0.851	36.66^b±0.779	35.77^b±0.851	34.75^b±0.75	<0.01	0.043	0.439
ST	39.84^a±0.476	38.72^{ab}±0.436	38.30^{bc}±0.476	37.22^c±0.425	<0.001	0.014	0.956

a-c Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.
* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

The effect of subspecies and sex on the cooking loss percentage for different muscles is presented in Table 5.2. Significant subspecies and sex effects were present for the cooking loss percentage of the LTL, BF, SM and ST, where the Damara subspecies and male springbok had the highest cooking loss percentage

The effect of subspecies and sex on the shear force (N) of the different muscles are presented in Table 5.4, where there were interactions between subspecies and sex for SM (P<0.001). Subspecies (P<0.001) and sex (P <0.001) effects were present for the LTL, BF and ST, where Damara subspecies and males had the higher shear force values.

Table 5.3 The effect of sex and subspecies (Damara vs Karoo) on the shear force (N) of different muscles (Least square means ± SE)

	Damara		Karoo		P-value		
Shear force (N)	**Male n=10**	**Female n=10**	**Male n=10**	**Female n=10**	**Sub species**	**Sex**	**Sub X Sex**
LTL	24.38^{a}±1.799	21.09^{ab}±1.909	20.55^{b}±1.899	15.09^{c}±1.682	<0.01	<0.001	0.413
BF	34.56^{a}±2.551	27.22^{b}±2.675	26.11^{b}±2.636	15.52^{c}±2.541	<0.001	<0.001	0.203
SM	32.82^{a}±2.638	28.33^{b}±2.781	25.91^{b}±2.722	12.57^{c}±2.578	<0.001	<0.001	<0.01
ST	39.92^{a}±1.603	22.84^{b}±1.691	23.91^{b}±1.678	17.46^{c}±1.542	<0.001	<0.001	0.749

$^{a-c}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.
* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

The effect of subspecies and sex on colour is presented in Table 5.5; there were interactions between subspecies and sex for the L* values of the LTL (P<0.001) and SM (P < 0.001). Karoo males had a higher L* value for the LTL than Karoo females, whereas Damara males and females recorded similar L* values. Damara males recorded lower L* values for the SM than Damara females. Where Karoo males recorded higher L* values for the SM than Karoo females. Karoo subspecies also had higher L* values in comparison to the Damara subspecies for the BF (P<0.001) and ST (P<0.001).

There were interactions between subspecies and sex for a* values of the LTL (P<0.01), BF (P=0.011) and ST (P<0.010). Karoo females recorded higher a* values for the LTL and ST than Karoo males, where Damara males and females had similar a* values for the LTL and ST. For the BF muscle, the Damara males had a significantly higher a* value than the Damara females and Karoo males, but Karoo males and females did not differ for a* value. The Karoo subspecies had higher a* values than Damara subspecies for the SM (P<0.001).

There were subspecies effects for the b* values of the BF (P<0.001), SM (P=0.036), and ST (P = 0.029), where the Karoo subspecies had significantly higher b* values for all three muscles. The Karoo subspecies also had higher hue-angle value for the BF (P<0.01).

There were interactions between subspecies and sex for the C* value of the LTL (P<0.01), BF (P<0.001), and ST (P<0.001). The Damara males had a higher C* value for the LTL and BF than the Damara females, whereas the Karoo males and females had similar C* values. The Karoo females recorded higher C* values for the ST than the Karoo males, whereas Damara males and females had similar C* values for the ST. The Karoo subspecies also had higher C* values for the SM (P<0.001).

Pooled means for parameters that differed significantly are reported in addendum 5.1 and 5.2.

Table 5.4 The effect of subspecies (Damara vs Karoo) and sex on the colour parameters of springbok meat (Least square means ± SE)

Colour Parameters		Damara		Karoo		P-value		
		Male n=10	Female n=10	Male n=10	Female n=10	Sub species	Sex	Sub X Sex
L*	**LTL***	29.7^{b}±0.395	29.43^{b}±0.368	31.23^{a}±0.384	29.24^{b}±0.358	<0.001	<0.001	<0.001
	BF	29.30^{b}±0.386	29.16^{b}±0.395	31.9^{a}±0.405	31.97^{a}±0.362	<0.001	0.907	0.716
	SM	29.44^{c}±0.337	30.46^{ab}±0.352	30.90^{a}±0.351	30.23^{b}±0.322	<0.001	0.472	<0.001
	ST	32.38^{b}±0.423	33.78^{a}±0.437	33.34^{a}±0.444	34.04^{a}±0.399	<0.01	<0.01	0.229
a*	**LTL**	12.97^{ab}±0.184	12.55^{b}±0.272	12.58^{b}±0.283	13.32^{a}±0.249	0.281	0.495	<0.01
	BF	13.76^{a}±0.280	13.16^{b}±0.287	13.20^{b}±0.294	13.63^{ab}±0.263	0.769	0.700	0.011
	SM	13.41^{bc}±0.313	12.98^{c}±0.322	13.77^{ab}±0.328	14.18^{a}±0.296	<0.001	0.959	0.051
	ST	14.48^{b}±0.221	14.55^{b}±0.226	14.24^{b}±0.232	15.36^{a}±0.207	0.024	<0.01	<0.001
b*	**LTL**	7.42±0.299	7.15±0.292	7.69±0.207	7.41±0.275	0.261	0.335	0.992
	BF	7.93^{ab}±0.339	7.26^{b}±0.348	8.28^{a}±0.367	8.24^{a}±0.317	<0.001	0.231	0.187
	SM	8.18±0.280	8.25±0.272	8.53±0.307	8.71±0.256	0.036	0.638	0.800
	ST	8.91^{ab}±0.280	8.70^{b}±0.285	8.99^{ab}±0.305	9.37^{a}±0.261	0.029	0.726	0.149
h_{ab}	**LTL**	29.66±1.191	29.77±1.157	31.30±1.327	29.25±1.095	0.551	0.394	0.300
	BF	28.68^{b}±1.109	29.06^{b}±1.087	31.95^{ab}±1.218	31.25^{a}±1.019	<0.01	0.518	0.968
	SM	31.36±0.891	31.23±0.815	31.92±0.972	31.10±0.799	0.774	0.571	0.660
	ST	31.49±0.747	30.94±0.721	32.12±0.821	31.29±0.682	0.357	0.322	0.814
C*	**LTL**	15.09^{a}±0.252	14.54^{b}±0.262	14.88^{ab}±0.278	15.34^{a}±0.252	0.062	0.823	<0.01
	BF	15.83^{a}±0.305	14.99^{b}±0.320	15.50^{ab}±0.324	15.91^{a}±0.0.29	0.048	0.345	<0.001
	SM	15.64^{bc}±0.346	15.47^{c}±0.360	16.17^{ab}±0.372	16.00^{a}±0.329	<0.001	0.639	0.188
	ST	16.94^{b}±0.268	16.93^{b}±0.282	16.74^{b}±0.286	18.04^{a}±0.256	<0.001	<0.001	<0.001

$^{a-c}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.
* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

5.4.2 Intensity of Culling (Trial 2)

The effect of intensity of culling and sex on the pH and temperature are presented in Table 5.6. There were differences between levels of intensity of culling in the pH_u of the SM (P=0.025) and ST (P=0.0212), where the Wellington springbok had higher pH_u than the Witsand springbok for both muscles. There were no significant differences between intensity of culling levels for the LTL and BF. Sex had no influence in the pH_u for any of the muscles.

Table 5.5 The effect of intensity of culling on pH_u for male and female Karoo springbok (Least square means ± SE)

pH_u	Wellington (low intensity)		Witsand (high intensity)		P-value		
	Male n=10	Female n=10	Male n=10	Female n=10	Cull	Sex	Cull X Sex
LTL*	5.50±0.110	5.47±0.111	5.37±0.124	5.25±0.121	0.202	0.494	0.671
BF	5.56±0.064	5.52±0.064	5.39±0.072	5.41±0.070	0.081	0.920	0.581
SM	5.56±0.064	5.55±0.064	5.37±0.072	5.38±0.070	0.025	0.975	0.854
ST	5.54±0.049	5.48±0.049	5.34±0.049	5.40±0.054	0.021	0.811	0.155

* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

The effect of intensity of culling and sex on the drip loss percentage is presented in Table 5.6, where there was an interaction between intensity of culling and sex for the LTL (P = 0.022). The Wellington females had a lower drip loss percentage than the Wellington males, whereas the Karoo males and females did not differ for the drip loss percentage of the LTL. The Witsand farm also had higher drip loss for the ST (P < 0.01).

Table 5.6 The effect of intensity of culling on cooking loss % and drip loss % for male and female Karoo springbok (Least square means ± SE)

Drip Loss %	Wellington (low intensity)		Witsand (high intensity)		P-value		
	Male n=10	Female n=10	Male n=10	Female n=10	Cull	Sex	Cull X Sex
LTL*	1.77^{a}±0.181	1.18^{b}±0.167	1.75^{a}±0.195	1.94^{a}±0.190	0.077	0.234	0.022
BF	1.07±0.097	1.16±0.091	1.24±0.103	1.41±0.128	0.831	0.306	0.642
SM	1.31±0.118	1.68±0.160	1.79±0.212	1.81±0.160	0.508	0.320	0.353
ST	0.97^{bc}±0.088	0.93^{c}±0.073	1.19^{ab}±0.124	1.29^{a}±0.124	<0.01	0.663	0.596
Cooking Loss %							
LTL	33.77^{a}±0.955	30.38^{b}±0.929	32.40^{ab}±0.1.07	31.87^{ab}±1.053	0.964	0.038	0.127
BF	36.35^{a}±0.615	34.69^{a}±0.563	36.21^{a}±0.654	35.34^{a}±0.640	0.720	0.033	0.489
SM	36.40^{a}±0.764	34.86^{ab}±0.743	35.68^{ab}±0.861	33.76^{b}±0.842	0.333	0.024	0.794
ST	38.24^{a}±0.625	37.04^{a}±0.689	37.83^{a}±0.726	36.20^{a}±0.689	0.416	0.027	0.725

$^{a\text{-}b}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.
* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

The effect of intensity of culling and sex on the cooking loss percentage is presented in Table 5.6. There were differences in cooking loss percentage between the males and females for the LTL (P = 0.038), BF (P = 0.033), SM (P = 0.024) and ST (P = 0.027), where male springbok had the higher cooking losses.

The influence of the intensity of culling and sex on shear force (N) is presented in Table 5.7. There were differences between males and females for the LTL (P < 0.001),

BF (P=0.16) and ST (P=0.042), where male springbok had higher shear force values. There were also shear force differences between the Wellington and Witsand farms for the LTL (P<0.001), BF (P<0.001), SM (P=0.019) and ST (P<0.001), where the Wellington springbok had higher shear force values.

Table 5.7 The effect of intensity of culling on Shear force (N) for males and female Karoo springbok (Least square means ± SE)

Shear force (N)	Wellington (low intensity)		Witsand (high intensity)		P-value		
	Male	**Female**	**Male**	**Female**	**Cull**	**Sex**	**Cull X Sex**
LTL *	18.85±1.100	15.37±1.019	12.67±1.122	10.16±1.214	<0.001	<0.001	0.579
BF	20.71±1.201	18.89±1.202	16.77±1.219	13.37±1.360	<0.001	0.016	0.475
SM	18.97±1.139	16.96±1.042	15.9±1.194	14.95±1.267	0.019	0.124	0.617
ST	21.43±0.890	20.48±0.813	19.01±0.935	16.87±0.988	<0.001	0.042	0.470

* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

The effect of intensity of culling and sex on the colour parameters of the four economically important muscles are presented in Table 5.8. There were interactions between intensity of culling and sex for the L* value of the BF (P=0.036), SM (P<0.001) and ST (P<0.001), where the Witsand males and females had similar L* values for the BF, SM and ST. In contrast, the Wellington males had lower L* values than the Wellington females. The Witsand springbok had the higher L* values for the LTL (P< 0.001).

There were also interactions between intensity of culling and sex for the a* value of the LTL (P<0.001), BF (P<0.001), SM (P<0.001) and ST (P<0.001). The Wellington males had higher a* values than the Wellington females for all muscles, whereas the Witsand males had lower a* values than the Witsand females. For the LTL, BF, SM and ST the Witsand females had the highest a* value and the Wellington females had the lowest.

There were interactions between intensity of culling and sex for the b* values of the LTL (P=0.015). The Wellington males had higher b* values than the Wellington females, whereas the Witsand males had lower b* values in comparison to the Witsand females. The Witsand farm had the higher b* values for the BF (P<0.01), ST (P<0.01) and SM (P<0.001).

There was an interaction between sex and intensity of culling for the hue-angle of the BF (P<0.01). The Wellington males had a lower hue-angle than the Wellington females, whereas the Witsand males and females had similar hue-angle values. The Witsand (P=0.038) and female (P=0.040) springbok had the higher hue-angle values for the SM.

The chroma of the LTL (P=0.012) had an interaction between the main effects. The Witsand males and females differed for the LTL chroma value, whereas the Wellington males and females had similar chroma values. The Witsand females had the highest chroma value for the LTL, and the Wellington males and females had similar chroma values. The Witsand springbok had the higher chroma for the BF (P<0.001), SM (P<0.001) and ST (P=0.041).

Pooled means for parameters that showed significant differences are reported in addendum 5.3 and 5.4.

Table 5.8 The effect of intensity of culling on colour parameters for male and female Karoo springbok (Least square means ± SE)

Colour parameters		Wellington (low intensity)		Witsand (high intensity)		P-value		
		Male n=10	Female n=10	Male n=10	Female n=10	Cull	Sex	Cull X Sex
L*	LTL*	29.96^{b}±0.220	30.11^{b}±0.202	31.36^{a}±0.229	31.31^{a}±0.249	<0.001	0.784	0.620
	BF	31.26^{b}±0.249	32.42^{a}±0.228	31.19^{b}±0.259	31.36^{b}±0.282	0.014	<0.01	0.036
	SM	29.44^{b}±0.343	30.88^{a}±0.314	31.47^{a}±0.351	30.81^{a}±0.387	<0.001	0.131	<0.001
	ST	32.75^{b}±0.345	34.45^{a}±0.316	31.21^{c}±0.354	30.84^{c}±0.390	<0.001	0.012	<0.01
a*	LTL	14.94^{c}±0.597	11.98^{d}±0.574	16.75^{b}±0.601	18.54^{a}±0.638	<0.001	0.032	<0.001
	BF	15.76^{b}±0.618	12.18^{c}±0.602	16.41^{b}±0.621	18.62^{a}±0.648	<0.01	<0.001	<0.001
	SM	14.81^{c}±0.438	13.46^{d}±0.424	17.52^{b}±0.441	18.55^{a}±0.465	<0.001	0.373	<0.001
	ST	16.52^{b}±0.509	14.22^{c}±0.498	16.93^{b}±0.511	19.04^{a}±0.529	<0.001	0.577	<0.001
b*	LTL	8.28^{b}±0.425	7.42^{b}±0.374	9.92^{a}±0.422	10.93^{a}±0.480	<0.001	0.826	0.015
	BF	7.86^{c}±0.394	8.86^{bc}±0.345	9.18^{ab}±0.393	9.77^{a}±0.427	<0.01	0.024	0.566
	SM	14.81^{c}±0.438	13.46^{d}±0.424	17.52^{b}±0.441	18.55^{a}±0.465	<0.001	0.057	0.427
	ST	9.61^{b}±0.322	9.74^{b}±0.285	10.06^{b}±0.321	11.02^{a}±0.363	<0.01	0.043	0.144
h_{ab}	LTL	29.99±1.214	30.61±1.064	30.02±1.206	32.71±1.348	0.351	0.120	0.340
	BF	27.82^{b}±1.437	34.66^{a}±1.276	28.66^{b}±1.434	28.7^{b}±1.628	0.038	<0.01	<0.01
	SM	29.69^{b}±1.163	32.55^{a}±1.031	32.64^{ab}±1.16	33.82^{a}±1.314	0.038	0.040	0.414
	ST	30.68^{b}±0.997	33.79^{a}±0.906	29.99^{b}±1.000	31.62^{b}±1.143	0.056	<0.01	0.366
C*	LTL	15.85^{c}±0.452	15.54^{c}±0.407	17.36^{b}±0.452	18.97^{a}±0.522	<0.001	0.068	0.012
	BF	15.13^{c}±0.353	16.8^{b}±0.319	16.4^{b}±0.353	18.02^{a}±0.404	<0.001	<0.001	0.93
	SM	15.26^{c}±0.427	17.29^{b}±0.387	19.38^{a}±0.428	20.07^{a}±0.491	<0.001	<0.001	0.063
	ST	17.34^{b}±0.312	18.66^{a}±0.282	17.85^{b}±0.312	19.13^{a}±0.357	0.041	<0.00	0.929

$^{a-d}$ Superscripts within the same row with different letters, differ significantly (P≤0.05) between treatment groups.
* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

5.5 DISCUSSION

5.5.1 Subspecies comparison (Trial 1)

The Damara subspecies is much larger than the Karoo subspecies (Chapter 3), and larger springbok are sought after for meat production as well as trophy hunting. Larger springbok also allows for a higher income per springbok culled during the hunting season. Springbok is the most exported game meat (SADAFF, 2010) and is considered to have excellent meat quality characteristics (Hoffman, Kroucamp, & Manley, 2007a; Van Zyl & Ferreira, 2004; Von la Chevallerie, 1972). However, the studies that have determined this have predominantly been conducted on Karoo springbok and not on the Damara subspecies (Hoffman, Kroucamp, & Manley, 2007c; Hoffman *et al*., 2007a; Van Zyl & Ferreira, 2004; Von la Chevallerie, 1972). This study aimed to determine whether the Springbok subspecies differed in terms of meat quality.

The pH_u in the current study ranged from 5.43-5.53. The ultimate pH and rate that pH declines are very dependent on the amount of glycogen available for anaerobic glycolysis *post mortem* (Bond, Can, & Warner, 2004). Ultimate pH is usually between 5.3-5.7 in normal meat (Briskey *et al*, 1961). The pH_u observed for springbok subspecies fell within the accepted norm of 5.3-5.7. Thus, animals culled in this study were not under any excessive *ante mortem* stress factors that would influence the ultimate pH. The lack of sex-related pH differences was also found in a previous study for Namibian springbok (Hoffman *et al*.,2019).

In contrast findings for Karoo springbok from different production regions, yielded sex-related pH_u differences, although it should be considered that many females originating from the Caledon region in that trial had DFD meat caused by an inexperienced cropping team (Hoffman, Kroucamp, & Manley, 2007a). In impala, pH values of males were higher compared to female impala of similar ages; this was due to the increased level of activity and alertness exhibited by males during the rut season (Hoffman, 2000). In this study, both the Damara and Karoo springbok were culled in the early to late winter season, and so males were not in rut and thus had a decreased level of activity and did not differ from females for muscle pH_u.

Meat tenderness and WHC capacity influence consumers' willingness to purchase meat (Kerry & Ledward, 2009), tenderness has been reported to be especially important to consumers (Udomkun *et al*., 2018). The water holding capacity (WHC) of meat directly influences cooking loss and drip loss. WHC, in turn, is influenced by the rate at which pH declines relative to temperature as well as the ultimate pH of meat (Warris, 2000). The ultimate pH of 5.4-5.5 is close to the iso-electric point of meat (proteins within the muscle) (Huff-Lonergan & Lonergan, 2005). The iso-electric point is where electrostatic forces are decreased, and consequently, the myofilament space is decreased, decreasing the ability of meat to retain water (Offer *et al*., 1989; Offer, 1991; Offer & Cousins, 1992). As the ultimate pH of a non-stressed animal is generally between 5.3-5.7, some water loss is unavoidable (Briskey & Wismer-Pedersen, 1961). WHC decreases and cooking loss increases when meat has a low pH_u. Cooking loss percentage and tenderness are also highly related, and when the cooking loss of meat is low, the shear force values tend to be low, and thus the meat tends to be very tender (Lawrie, 2010; Okuskhanova *et al*., 2017). This is apparent in the current study where the Damara subspecies had a significantly higher cooking loss and drip loss than the Karoo subspecies (Table 5.2). Subsequently, the Damara subspecies had a higher shear force and thus lower tenderness (Table 5.3). Thus, Shear force values in this study increased with dead weight. Similarly, in a study of breed differences in lambs shear force increased with deadweight; the heavier breed having a higher shear force (Teixeira, Batista, Delfa, & Cadavez, 2005).

Differences in the rate that a carcass cools after slaughter can be dependent on the carcass size – a larger carcass will cool at a slower rate (Warris, 2000). The rate of temperature decline can influence the rate of pH decline and enzymatic degradation (Warris, 2000). Therefore, carcasses that cool at a slower rate have a higher level of protein denaturation, and thus increased myofibril shrinkage and a lower WHC (Honikel, Hamid, Fischer, & Hamm, 1981; Lawrie & Ledward, 2006; Warris, 2000). Therefore, it is speculated that the larger carcasses of the Damara subspecies cooled at a slower rate due their size and the ambient temperatures of between 22 - 25° in July 2019 in Namibia. In comparison, the smaller Karoo carcasses at an ambient temperature of between 6°C and 15°C in September 2019 could have cooled at a faster rate. The different subspecies' carcasses were also cooled under different conditions, where the Damara springbok were placed in chillers that were filled to capacity. In contrast, the Karoo springbok carcasses were placed alone in the chiller. These differences in cooling conditions could also have contributed to a difference in cooling rate between subspecies. As the pH decline and temperature decline were not measured in the current study, it can only be speculated that these chilling rate differences existed and could have caused the differences in cooking loss and subsequently tenderness as seen in the current study. As the different subspecies of springbok occurred in different countries and thus in different regions, it is also challenging to distinguish between intrinsic subspecies differences and differences due to the different regions/environments in which they occurred.

The Damara subspecies shear force values in this study were similar to Namibian springbok (Hoffman *et al*., 2019), whilst the Karoo Springbok shear force values in this study corresponded with Karoo springbok from different regions studied by Hoffman *et al*. (2007a). Although the Damara springbok had higher shear force values than the Karoo springbok, both subspecies still had lower shear force values than kudu (Mostert & Hoffman, 2007), impala

(Hoffman *et al*., 2009) and wildebeest (Van Heerden & Hoffman, 2018) for the same muscles. Shear force values less than 33N are classed as very tender, while values between 33N and 43N are classed as tender. Both Damara (29 N) and Karoo (19.64 N) shear force values were lower than 33N and so their muscles can be classed as very tender (Destefanis, Brugiapaglia, Barge, & Dal Molin, 2008) and will probably not be distinguishable from each other by the consumer. Thus, springbok tenderness independent of subspecies was ideal for high-quality meat production.

Male springbok also had a higher cooking loss (Table 5.2) and shear force (N) (Table 5.3) than females. Female animals have been reported to have a higher intramuscular fat content in comparison to their male counterparts, as was reported in springbok (Hoffman *et al*., 2007c) and impala (Hoffman, 2000). A higher intramuscular fat content is associated with an increased level of tenderness (Stevenson, Seman, & Littlejohn, 1992). Daszkiewicz *et al.*, (2012a) reported that female roe deer with a higher fat content had a lower shear force and thus higher tenderness than males with lower fat content. It is thus speculated that sex-related differences in the IMF content could have influenced the sex-related differences observed in tenderness.

Another possible cause for the sex-related tenderness differences could be differences in collagen content between sexes. Collagen content and collagen solubility greatly influence meat tenderness (Lepetit, 2007; Lepetit, 2008) and intact males have been reported to have higher collagen content and subsequently higher degrees of toughness (Boccard *et al*., 1979). The sex-related difference in collagen is thought to be due to the effect of testosterone on the synthesis of collagen (Gerrard *et al*., 1987).

The difference between males and females for shear force values in this study contrast to the lack of sex-related differences found in Karoo springbok (Hoffman *et al*., 2007a; Neethling, Muller, van der Rijst, & Hoffman, 2018) and Namibian springbok (Hoffman *et al*., 2019). It should be considered that the Namibian springbok were younger than the springbok in the current and it is well documented that older animals have tougher meat due to the increase in heat soluble collagen within their muscles.

Colour is noted to be a fundamental meat quality characteristic at point of purchase (Udomkun *et al*., 2018) as consumers use colour as a measure of freshness. Colour is influenced by a variety of factors such as diet, pH_u, myoglobin content, muscle fibre type, species, breed and sex (Neethling *et al*., 2017). Due to the complex nature of colour and the variety of factors that could influence colour measurements of game meat, all comparisons across studies were made considering the fact that study-specific effect could have influenced the measurements.

The Karoo subspecies had higher L*, a*, b*, and chroma values. Thus, the Karoo subspecies meat was lighter (higher L*), redder (higher a*), and more saturated (brighter) than the Damara subspecies' meat. pH_u significantly influences the colour of game meat (Hoffman *et al*., 2007a, 2009) and in turn, hunting practices, and so stress greatly influences the pH_u. A wounded and highly stressed impala was reported to have colour measurements (L* = 25.44, a* = 9.13, b* = 4.88; Hoffman, 2000) at a high pH. In our study, pH_u did not differ between any treatment groups or muscles, and probably did not influence the differences in colour measurements observed

Colour measurements between species can differ due to differences in myoglobin content and the proportion of muscle fibre types (Vestergaard, Oksbjerg, & Henckel, 2000). Myoglobin is the haem pigment that most influences colour of meat (Lawrie & Ledward, 2006). Game meat is commonly darker than domestic species' meat. This is because of a higher Mb content that is commonly associated with the greater degree of activity commonly seen in game in comparison to domestic species (Hoffman, Kritzinger, & Ferreira, 2005; Hoffman, 2000). The Damara subspecies had a much larger camp than the Karoo subspecies and could mean that the Damara springbok were more active than the Karoo springbok as they had to move over much larger distances. This increased physical activity could have increased Mb content giving the Damara springbok meat a darker colour.

Differences in diets can cause differences in meat colour (Lawrie & Ledward, 2006). Most studies focusing on dietary differences have focused on the effect that roughage versus concentrate has on the colour of meat (Muir, Deaker, & Bown, 1998; Priolo, Micol, & Agabriel, 2001). The range of studies that have focused on the effect that diet has on the colour of meat has thus far been very much limited to domestic species and very little research on dietary effect and feeding system effects on game meat have been studied (Neethling *et al*., 2017). Springbok are highly selective feeders and prefer a particular range of plant species (Bigalke, 1972). However, their daily diet can significantly differ between such drastically different regions as South Africa and Namibia. In one of the few studies on different regions' effect of game meat colour the presence of an inexperienced culling team and subsequent high pH_u values overshadowed the effect that different regions had on game (springbok) meat colour (Hoffman *et al*., 2007a). Differences in diets can affect colour through differences in constituents, but dietary differences throughout the lives of animals can also influence growth rates and body compositions and so influence colour (Muir *et al*., 1998). The differences observed between subspecies could possibly also have been due to differences in diets. The nature of the distribution of different subspecies means that their diets are very variable throughout their lives. As a range of factors influences colour, determining whether differences observed between subspecies is due to intrinsic genetic differences or due to environmental effects is challenging.

The Damara springbok (L* = 28.8-32.3; a* = 12.7-15.0; b* = 7.10-9.3) colour measurements were in the same range as previous measurements for Namibian springbok (Hoffman *et al*., 2019). The Karoo springbok (L* = 28.7-34.1; a* = 12.9-15.6; b* = 7.4-9.6) were similar to measurements for Karoo springbok from different regions (Hoffman *et al*., 2007a). These comparisons were made with the consideration that study-specific effects could have an influence on measurements. Both Damara and Karoo springbok had similar L* and a* values to mountain reedbuck (L* = 31.1-33.4; a* = 10.5-11.9; Hoffman, van Schalkwyk, & Muller, 2008) but higher L* and a* values than impala (L* = 28.78-29.66; a* = 11.1-11.4; Hoffman, 2000), and lower L* and a* values than beef (L* = 34.8-36.5; a* = 22.4-22.6) as recorded by Kim, Yoon, Song, & Lee, (2003). Both subspecies had L*< 33, low b* (±10), and high a* (>13) values for colour, which is commonly associated with 'normal' coloured game meat (Shange, Gouws, & Hoffman, 2019; Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003).

5.5.2 Intensity of culling comparison (Trial 2)

High intensity of selective culling means that all or most mature larger males are selected first and the average age of the males in the population decreases (Coltman *et al*., 2003; Festa-Bianchet *et al.*, 2014; Skinner & Louw, 1996). The meat quality implications of a higher intensity of culling have not been determined on any animal. This chapter aims to quantify whether the increased intensity of culling over a period influences the physical meat quality of springbok meat. This is important as a decreased physical meat quality could further add to the negative financial implications of high intensity of culling larger animals.

The combined pH_u ranged from 5.26-5.53 is within the range of 5.3-5.7 that is prescribed as the ultimate pH of typical meat in which no *ante mortem* stress factors affected the amount of glycogen available for *post mortem* glycolysis (Bond *et al*., 2004; Briskey & Wismer-Pedersen, 1961). Considering the range of pHu values, we may argue that over-culling did not increase *ante mortem* stress and that glycogen levels were not depleted before the culling took place. Although the animals on the Witsand farm were frequently culled, enough time elapsed between culls/hunts for animals to replenish glycogen reserves. The method of hunting that was used (night hunt and headshots) could also have aided in this as the springbok did not run for extended periods of time (Hoffman, 2000).

Tenderisation decreases in the early *post mortem* phase between pH_u of 5.8-6.3 (Yu & Lee, 1986), where after shear force values have been noted to decrease in lambs and thus tenderisation increases at pH_u above 6.3 (Devine, Graafhuis, Muir, & Chrystall, 1993). Shear force values are also highly correlated to cooking loss percentage values where an increase in cooking loss is correlated with higher shear force values and thus decreased tenderness (Lawrie, 2010). Neither pH_u nor cooking loss percentage differed between farms, and both pH_u and cooking loss percentage was moderate and so shear values were low.

The negative consequence of selective culling, in which males are selectively culled is that most if not all older males are culled and only younger (though still mature) males are left in the herd/population. Thus, the average age of males within the herd would be much younger in an intensively culled herd than in a herd in which culling is more infrequent (Coltman *et al*., 2003; Skinner & Louw, 1996). The difference in shear force observed between the Wellington and Witsand could to some extent have been influenced by the age differences between Wellington males and Witsand males. Although Hoffman *et al*. (2007a) reported that age did not influence the shear force of Karoo springbok meat from different regions.

The differences in tenderness reported in this study were not exclusively between Wellington and Witsand males. The Witsand females also had a decreased tenderness in comparison to the Wellington females. This suggests that differences in tenderness were not only due to the effect of intensity of culling (age). When the field notes were consulted, it was noted that the Wellington springbok were shot at a far greater distance than the Witsand springbok. This distance was due to the far greater flight zones of the Wellington springbok; there was thus a higher degree of excitability in the Wellington springbok. Cattle with a higher degree of excitability have been reported to have higher shear force values than their calmer counterparts, and excitability was thought to cause a reduction in proteolysis and thus tenderness (King *et al*., 2006).

Meat is considered very tender when shear force values of less than 33N are obtained. Wellington and Witsand springbok differed significantly for shear force values (Table 5.6), but both had shear force values less than 33N and could thus be classified as very tender (Destefanis *et al*., 2008). The consumer cannot necessarily distinguish between meats within the very tender classification (Destefanis *et al*., 2008). Shear force values for both farms are similar to values obtained for Karoo springbok from different regions (Hoffman *et al*., 2007a) and both farms' springbok had shear force values much lower than kudu (Mostert & Hoffman, 2007), wildebeest (Van Heerden & Hoffman, 2018), and impala (Hoffman *et al*., 2009). Male springboks' meat was tougher than that of female springbok (Table 5.7), as previously discussed these sex-related differences in shear force could be due to differences in the IMF content and differences in collagen content between male and female springbok.

There were significant interactions between intensity of culling (farm) and sex for the L* colour values of the BF, SM, and ST. In previous chapters (Chapter 3 and 4), it was reported that increased intensity of culling seemed to diminish the sex-related differences on the Witsand farm. The interaction seen in colour could be because Wellington males had lower L* values than Wellington females. In contrast the Witsand males and females had similar L* values. The meat of male game animals has been noted to be darker than that of females. As previously discussed, myoglobin content influences the colour of meat. The darker meat of males is attributed to an increased amount of activity of males in comparison to females and thus an increased level of myoglobin (Hoffman, 2000). The Wellington males had lower L* value than the Wellington females, whereas the Witsand males did not differ in L* values from the Witsand females. Springbok males are highly territorial, and breeding males actively defend their territories (Skinner & Louw, 1996). The drastically decreased number of mature breeding males left, after most had been selectively culled on the Witsand farm, could have led to males not as actively defending their territory as there were not enough males to continually challenge each other's territories. Therefore, the Witsand males did not exhibit the typically darker meat as has been reported in Wellington males.

All the springbok in the current study had colour values that were common for game meat and fell within the acceptable normal range for fresh meat sales (L* < 33, a* <13, b*±10) (Shange *et al.*, 2019). It has been reported that meat with an a* value above 14.5 is perceived as acceptable to consumers (Holman, van de Ven, Mao, Coombs, & Hopkins, 2017). Only the Wellington females had a* values lower than this threshold, and so the Witsand springbok and Wellington males should be well received by consumers. Due to the complex nature of colour and the multitude of factors that can influence it, it should also be considered that other factors such as diet and season could also influence colour values (Kim *et al.*, 2003; Neethling *et al.*, 2017). The Wellington springbok were culled in September, and the Witsand springbok were culled in June. The difference in seasons and thus the veld condition could have influenced the colour differences observed between the farms.

5.6 CONCLUSION

Physical meat quality is important to measure to assure consumer acceptance. Springbok subspecies differed significantly for most physical meat quality parameters, but these differences were minimal. The Karoo subspecies had a lower shear force, but both subspecies' shear force fell within the tender range (<33N). Cooking loss % and drip loss % was higher in the Damara subspecies, but both subspecies still fell within the normal, acceptable cooking loss % and drip loss %. There is not necessarily a marketable and, thus, an economic advantage of one subspecies above the other in terms of physical meat quality.

The intensity of culling did not influence the pH_u, cooking loss %, drip loss %. The intensity of culling did have some influence on the colour measurements, but colour values for both farms were still within the normal range for game meat. Wellington springbok had higher shear force values than Witsand springbok but, the shear force of both farms' springbok was within the very tender range (<33N). If enough time elapses between hunts for the animals to replenish their glycogen reserves, or if culling is conducted in such a way (e.g., night culling) that the animals experience the least amount of stress possible, then intensive culling does not seem to change meat quality of a springbok population. High intensity of selective culling did influence the carcass yield (Chapters 3 and 4), but it did not influence the physical meat quality to an extent where it could incur financial losses or consumer aversion.

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ADDENDDUM 5.1: The effect of subspecies (Damara vs Karoo) and sex on the drip loss percentage, cooking loss percentage and shear force (N) (Least square means ± SE)

Parameter	Subspecies		Sex		P-value	
	Damara	Karoo	Male	Female	Subspecies	Sex
Drip Loss %						
SM	2.90±0.162	1.67±0.161	1.96±0.179	2.60±0.145	<0.001	<0.01
ST	1.94±0.110	0.88±0.110	1.27±0.123	1.55±0.099	<0.001	0.039
Cooking loss %						
LTL	35.22±0.675	32.30±0.633	35.32±0.726	32.21±0.601	<0.001	<0.001
BF	38.16±0.504	35.54±0.481	37.85±0.552	35.85±0.450	<0.001	<0.01
SM	37.73±0.641	35.26±0.602	37.29±0.689	35.70±0.571	<0.01	0.043
ST	39.28±0.359	37.76±0.337	39.07±0.386	37.97±0.320	<0.001	0.014
WBSF						
LTL	22.74±1.591	17.82±1.492	29.36±2.553	20.45±2.52	<0.01	<0.01
BF	30.89±2.425	28.82±2.315	30.33±2.478	21.37±2.468	<0.001	<0.001
ST	26.38±1.471	20.68±1.416	26.91±1.528	20.148±1.474	0.413	0.413

ADDENDDUM 5.2: The effect of subspecies (Damara vs Karoo) and sex on the colour measurements (Least square means ± SE)

Colour		Subspecies		Sex		P-value	
		Damara	Karoo	Male	Female	Subspecies	Sex
L*	BF	29.23±0.333	31.94±0.319	30.60±0.358	30.56±0.331	<0.001	<0.001
	ST	33.08±0.372	33.69±0.356	32.86±0.396	33.91±0.370	0.907	0.907
a*	SM	13.33±0.300	14.22±0.287	13.72±0.327	13.83±0.295	<0.001	0.959
b*	BF	7.59±0.292	8.26±0.282	8.10±0.320	7.75±0.292	<0.001	0.231
h_{ab}	BF	29.37±0.898	31.60±0.872	30.81±1.017	30.15±0.877	<0.01	0.518
C*	SM	15.55±0.307	16.38±0.297	15.90±0.331	16.035±0.310	<0.001	0.639
	SM	16.28±0.333	19.73±0.387	17.32±0.337	18.68±0.382	<0.001	<0.001
	ST	18.00±0.243	18.49±0.282	17.59±0.246	18.89±0.279	0.041	<0.00

ADDENDDUM 5.3: The effect of intensity of culling and sex on the drip loss percentage, cooking loss percentage and shear force (N) of Karoo springbok (Least square means ± SE)

	Intensity of culling		Sex		P-value	
	Wellington	**Witsand**	**Male**	**Female**	**Subspecies**	**Sex**
Cooking loss %						
LTL	32.08±0.658	32.13±0.868	33.09±0.628	31.12±0.737	0.960	0.038
BF	35.52±0.404	35.78±0.530	36.28±0.384	35.02±0.450	0.720	0.033
SM	35.63±0.526	34.72±0.694	36.04±0.503	34.31±0.589	0.333	0.024
ST	37.64±0.431	37.01±0.572	38.03±0.424	36.62±0.482	0.416	0.027
WBSF						
LTL	17.11±0.898	11.42±1.014	12.76±0.993	15.76±0.900	<0.001	<0.001
BF	19.80±0.878	15.07±0.878	16.13±0.142	18.74±0.864	<0.001	<0.001
ST	20.96±0.629	17.94±0.796	18.68±0.632	20.22±0.6321	<0.001	<0.001

ADDENDDUM 5.4: The effect of intensity of culling and sex on colour measurements of Karoo springbok (Least square means ± SE)

		Intensity of culling		Sex		P-value	
		Wellington	**Witsand**	**Male**	**Female**	**Subspecies**	**Sex**
L*	**LTL**	29.94±0.181	31.35±0.233	30.69±0.181	30.60±0.216	<0.001	0.784
b*	**BF**	8.36±0.264	9.48±0.338	8.52±0.266	9.31±0.315	<0.01	<0.01
	ST	9.68±0.231	10.54±0.283	9.83±0.235	10.38±0.324	0.024	0.024
h_{ab}	**SM**	31.12±0.842	33.23±1.025	31.165±0.855	33.19±0.994	0.038	0.040
	ST	32.23±0.791	30.81±0.908	30.34±0.800	32.71±0.900	0.056	<0.01
C*	**BF**	15.96±0.277	17.21±0.320	15.76±0.280	17.41±0.317	<0.001	<0.001
	SM	16.28±0.333	19.73±0.387	17.32±0.337	18.68±0.382	<0.001	<0.001
	ST	18.00±0.243	18.49±0.282	17.59±0.246	18.89±0.279	0.041	<0.00

CHAPTER 6

THE EFFECT OF SUBSPECIES AND SEX ON THE PROXIMATE COMPOSITION OF SPRINGBOK (*ANTIDORCAS MARSUPIALIS*) MEAT.

ABSTRACT

The effects of subspecies (Damara vs Karoo) and sex on the chemical composition of the *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST) and *Supraspinatus* (SS), were investigated. The moisture content did not differ significantly between subspecies or between sexes except for the LTL and varied between 71.7 – 77.0 g/100g for the pooled muscles. There were no significant subspecies differences for the intramuscular fat (IMF) content which varied between 2.0 – 4.1 g/100g for the pooled muscles. However, female springbok had higher IMF content than male springbok. The protein content of female springbok was higher than that of males for the LTL muscle. The protein content varied between 19.8 – 23.5 g/100g for the pooled muscles. The ash content had no significant sex and subspecies effects and varied between 1.2 – 2.0 g/100g. The Damara and Karoo subspecies did not differ in terms of chemical composition and the differences observed in IMF between male and female springbok were minimal and would not necessarily have a nutritive or marketable effect.

Keywords: Springbok subspecies, protein, IMF, moisture, ash

6.1 INTRODUCTION

The perception of game meat by local consumers is that it has low-fat content and is therefore healthier than the meat of domestic species (Hoffman, Muller, Schutte, Calitz, & Crafford, 2005; Wassenaar, Kempen, & van Eeden, 2019). Modern consumers have become very health conscious, and food with an increased nutritional value is particularly sought after; knowledge of the nutrient value of meat allows consumers to make decisions based on the nutritional composition (IGS, 2018). To this end, accurate, easily understood labelling of the chemical composition of meat is important because species and breeds have different chemical compositions and thus different nutritive values (Shannon, 1994; Shine, O'Reilly, & O'Sullivan, 1997).

Game species, especially springbok, are highly adapted to harsh arid environments (Furstenburg, 2016; Skinner & Louw, 1996). This is illustrated by the fact that springbok are both browsers and grazers and so can utilise a diverse spectrum of flora and are mostly independent of water (Bigalke, 1970; Bothma & Du Toit, 2010). This allows ranchers to produce meat in regions/areas in which domestic species cannot thrive (Cole, 1990). Game species can produce equal or higher amounts of lean meat in veld conditions without supplementation than traditionally farmed livestock such as cattle (Hopcraft, 1980). Game species have the potential to be utilised as both a source of high-quality nutrients and a source of protein-rich food to the ever-growing population (Suman & McMillin, 2014).

The nutritional value of meat is determined by its chemical composition that is subdivided into moisture, IMF and protein, ash (includes vitamins and carbohydrates); these components make up approximately 100 % of meat (Ang, Young, & Wilson, 1984). The chemical (proximate) composition of meat is influenced by a variety of factors such as age, sex, breed/species, production region and diet (Lawrie & Ledward, 2006; Olsson & Pickova, 2005). Game species have a lower IMF than domestic species (Hoffman & Wiklund, 2006). There is also an inverse correlation between IMF and protein; thus game species with their lower IMF content have a higher protein percentage than domestic species (Bureš, Bartoň, Kotrba, & Hakl, 2015; Williams, 2007). The negative correlation between moisture and IMF in meat also results in game species' meat having a higher moisture content than most domestic species (Sebranek, 2014; Williams, 2007).

The effect of region, age and sex on the proximate composition of the Karoo springbok subspecies (Hoffman, Kroucamp, & Manley, 2007; Van Zyl & Ferreira, 2004) as well as the effect of age and sex for the Kalahari subspecies (Hoffman, van Schalkwyk, & McMillin, 2019) has been determined. However, the chemical composition of the Damara subspecies has not been reported as of yet. This study aimed to determine the proximate composition of five muscles derived from two different springbok subspecies; namely the Karoo and Damara subspecies. This study also aimed to determine whether sex (male and female) differed per subspecies in terms of proximate composition.

6.2 METHODS AND MATERIALS

6.2.1 Animals and study location

Forty animals were culled over two months on two different farms. Twenty animals were culled (10 rams and 10 ewes) on each farm, and only mature animals were selected. Trial 1 (Subspecies comparison) consisted of 40 Springbok; 20 Damara (*A.m. angolensis*) and 20 Karoo (*A. m. marsupialis*). Age of all animals was determined by differences in dentition (Dewar, Halkett, Hart, Orton, & Sealy, 2006). Age of animals was determined by wear and tear of teeth (Dewar, Halkett, Hart, Orton, & Sealy, 2006). Damara and Karoo (Wellington) springbok were between 18 months and five years old. Refer to Chapter 3, Section 3.2.1 for a more detailed description of the study locations.

6.2.2 Culling and dressing

All the animals were harvested using the same procedure. Animals were shot in the head with a .243 calibre rifle (Ethical Clearance Number: 10NP_HOF02). The animals were then exsanguinated within two minutes of killing. Afterwards, the animals were loaded onto the hunting vehicle and were transported back to the designated slaughter area within two hours *post mortem*. At the slaughtering area, the carcasses were unloaded and eviscerated in the prescribed method (van Schalkwyk & Hoffman, 2010) by an experienced team. The carcasses were then chilled at 4°C for 24 hours. A more detailed description of the culling and dressing is given in Chapter 3, Section 3.2.2.

6.2.3 Sample preparation

Carcasses were removed after 24 hours from the refrigeration units, and divided in half, as described in Chapter 3. The left side of each carcass was used for the cutting test, as described in Chapter 3. The muscles used for physical meat quality and chemical composition were removed from the right side of the carcass. The following muscles were removed: *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Semitendinosus* (ST) and *Supraspinatus*. The chemical analysis samples were then cut from the centre of each muscle (approx. 150g), and the remaining muscle was used for physical analysis. Samples were then placed in labelled plastic bags, vacuum-sealed and frozen at -18˚C to -20˚C.

6.2.4 Chemical analysis

The samples were removed from the -20˚C freezer and placed in the chiller (4˚C) to thaw overnight. All external collagen tissue and visible external fat were removed from the samples, prior to sample homogenisation. The homogenised sample was then placed into a new labelled plastic bag, vacuumed, and stored at -20˚C.

All proximate analyses were done in duplicate for each sample and values were pooled. Analysis with an error larger than 20% between duplicates of a sample was repeated.

Fat content (g/100g) was determined by using the method prescribed by Lee *et al*. (1996) using a 1:2 chloroform/methanol ratio, as is recommended for game animals. A 5g homogenised sample was used to conduct the solvent extraction, and fat was determined from the residue of the 5ml chloroform that was left to evaporate for 45 minutes. The filtrate that remained after the fat analysis was then dried in a 60˚C oven.

Crude Protein (g/100g) was determined by grinding the de-fatted filtrate after it had dried at 60˚C for two days. A Leco Nitrogen/Protein Determinator (FP528-Leco Corporation) was used to determine the crude protein of a one-gram sample that was wrapped in a Leco^{TM} tinfoil sheet according to the Dumas combustion method, AOAC official method 9992.15 (AOAC international, 2002). To determine the crude protein (g/100), the %Nitrogen was multiplied by a factor of 6.25.

Moisture (g/100g) was determined using a 2.5g homogenised sample that was dried for 48 hours at 100˚C, as prescribed by the AOAC official method 943.01 (AOAC international, 2002). Ash content (g/100g) was then determined by placing the dried samples in a 500˚C oven for six hours as prescribed by the AOAC official method 942.05 (AOAC international, 2002).

6.2.5 Statistical Analysis

Statistical analysis was done using the STATISTICA 64 version 13.4 (2018) VEPAC model. The experimental design was a 2x2 factorial design with subspecies (Damara and Karoo) and sex (male, female) as the two main effects. A two-way ANOVA (univariate analysis of variance) was constructed using the Mixed model of STATISTICA per muscle to test for significant differences between main effects (subspecies and sex) and for significant interaction of main effects (subspecies x sex). Age was also included as a covariate. Correlations were calculated between the IMF and protein, and between IMF and moisture contents using Pearson's correlation coefficients. Shapiro-Wilk was used to test the underlying assumption of normality (Shapiro, Wilk & Unwin, 2013), and Levene’s test was conducted to test for deviation from homoscedasticity.

6.3 RESULTS

The effect of subspecies (Damara vs Karoo) and sex on the chemical composition of springbok meat is reported in Table 6.1, where subspecies had no effect on the chemical composition of springbok meat. Sex did influence the chemical composition; the moisture content of males was higher than females for the LTL ($P<0.01$). The LTL ($P=0.026$) protein content also differed between male and female springbok, where the female springbok had a higher protein percentage for the LTL. There was an interaction between subspecies and sex for the fat percentage of the SM ($P=0.031$). This interaction was likely because the Karoo females had a higher fat percentage than their male counterparts, whereas the Damara males and females had similar fat percentages for the SM whilst the Karoo females had the highest fat percentage for the SM, and the Karoo males the lowest. The fat percentage of the LTL ($P=0.029$), BF ($P<0.01$), ST ($P<0.01$) and SS ($P=0.011$) differed between males and females, where the female springbok had a higher fat percentage for the above-mentioned muscles. Sex did not influence the ash content of any of the muscles.

Table 6.1 The effect of subspecies (Damara vs Karoo) and sex on the proximate composition (%) of springbok meat (Least square means ± SE)

		Damara		Karoo		P-*value*		
		Male n=10	**Female n=10**	**Male n=10**	**Female n=10**	**Sub species**	**Sex**	**Sub X Sex**
MOISTURE	**LTL**	77.0^{a}±1.128	73.1^{bc}±1.086	75.1^{ab} ±1.187	71.7^{c}±1.094	0.115	<0.01	0.856
	BF	74.1±1.022	73.1±0.882	73.5±.985	72.6±0.972	0.497	0.281	0.891
	SM	73.5±1.402	73.1±1.202	74.6±1.225	72.1±1.131	0.933	0.222	0.343
	ST	74.8±1.522	74.5±1.216	75.1±1.330	73.8±1.123	0.850	0.554	0.729
	SS	76.6±1.229	75.2±0.982	75.9±1.112	74.5±1.032	0.495	0.187	0.955
PROTEIN	**LTL**	20.3^{b}±1.163	22.4^{ab}±0.983	20.9^{ab}±1.075	23.5^{a}±0.992	0.354	0.026	0.825
	BF	21.9±1.265	20.4±1.042	22.2±1.165	21.5±1.150	0.509	0.314	0.716
	SM	22.6±1.532	22.5±1.224	21.8±1.339	23.2±0.122	0.994	0.615	0.517
	ST	21.9±1.503	20.9±1.247	21.6±1.360	20.4±1.217	0.788	0.383	0.926
	SS	19.9±1.135	19.8±1.117	20.5±1.220	20.0±1.132	0.699	0.766	0.861
FAT	**LTL**	2.8^{b}±0.316	3.1^{ab}±0.300	2.8^{b}±0.316	3.9^{a}±0.292	0.169	0.029	0.177
	BF	3.0^{b}±0.367	3.8^{ab}±0.324	2.9^{b}±0.355	4.1^{a}±0.327	0.778	<0.01	0.510
	SM	2.9^{ab}±0.426	2.7^{ab}±0.373	2.1^{b}±0.409	3.5^{a}±0.391	0.946	0.095	0.031
	ST	2.6^{bc}±0.390	3.0^{ab}±0.354	2.0^{c}±0.375	3.8^{a}±0.359	0.796	<0.01	0.045
	SS	2.9^{a}±0.424	3.6^{ab}±0.372	2.5^{b}±0.421	3.8^{a}±0.375	0.704	0.011	0.304
ASH	**LTL**	1.3±0.154	1.5±0.154	1.3±0.168	1.2±0.132	0.176	0.792	0.370
	BF	1.6±0.124	1.4±0.127	1.5±0.132	1.4±0.109	0.538	0.135	0.744
	SM	1.4^{b}±0.206	2.0^{a}±0.241	1.3^{b}±0.220	1.3^{b}±0.181	0.071	0.121	0.098
	ST	1.5±0.081	1.5±0.088	1.2±0.070	1.4±0.085	0.178	0.908	0.666
	SS	1.4±0.096	1.4±0.106	1.3±0.106	1.2±0.085	0.220	0.595	0.603

$^{a-c}$ Superscripts within the same row with different letters differ significantly (p≤0.05) between treatment groups.
* *Longissimus thoracis et lumborum* (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM) and *Semitendinosus* (ST) and *Infraspinatus* (IS).

Table 6.2: Pearson's correlations between chemical components of springbok meat

Chemical component (%)		**Pearson**	***p*-value**
Protein%	Fat%	-0.44	<0.01
Protein%	Moisture%	-0.89	<0.01
Fat%	Moisture%	0.12	0.12

6.4 DISCUSSION

The objective of this study was to determine the proximate composition of both sexes of two springbok subspecies (Damara vs Karoo). The Damara subspecies is much larger and therefore heavier than the Karoo subspecies as reported in Chapter 3 and Chapter 4. This increased size has certain financial benefits as heavier springbok will mean a higher income per animal when hunters pay per carcass weight. The heavier springbok also has a lower culling/harvesting cost per kilogram. These economic benefits have made Damara springbok a desirable option for ranchers, but no research has been done on the subspecies meat's nutritional composition.

Skeletal muscles generally have a proximate composition of ~75 % moisture, ~20% protein and between 1 to 10% IMF. Skeletal muscles also consist of an added ~1% carbohydrates and ~1 % vitamins and minerals that are mostly reported as ash (Huff-Lonergan & Lonergan, 2005; Listrat *et al*., 2016; Olsson & Pickova, 2005). A comparison between studies is challenging as the chemical composition of meat is dependent not only on species but differences in age, sex, season and diet between different studies, even when the species is the same. Studies also differ in terms of sample sizes and proximate determination methods. This is illustrated in the differences in IMF percentage for red deer (*cervus elaphus*) between studies. Okuskhanova *et al*, (2017), reported IMF percentages in red deer of 2.3 %, whereas Bureš *et al*, (2015) reported IMF values of 0.8 %. Thus, comparisons made in this study take into account that a cross-study comparison is challenging and can merely illustrate a tendency.

Despite the size differences between subspecies' muscles (Chapter 4), the fat and subsequently protein content did not differ between subspecies (Table 6.1). The springbok also came from different regions, but this did not influence the chemical composition as region has been reported to do in Karoo springbok from different regions in South Africa (Hoffman *et al*., 2007). This could have been due to the fact that the study by Hoffman *et al,* (2007) had a much larger sample size per region than in the current study. In Impala, a region effect was only reported for the protein content (Hoffman, Kritzinger, & Ferreira, 2005).

The moisture content in the current study was inversely correlated with protein content (Table 6.2). This relationship is thought to be because water and protein are contained within the same lean portion of meat (Aidoo & Haworth, 1995). Female springbok had higher protein content for the LTL and due to the negative correlation between protein and moisture, female springbok also had a lower moisture content in comparison to male springbok. Similarly, female springbok from different regions had higher moisture contents for the loin (Hoffman *et al*., 2007a). The pooled moisture content ranged between 72.1 – 76.6 %, which was similar to previously reported moisture content of springbok from different regions (72.8 – 75.10 %; Hoffman *et al*., 2007) and Namibian Kalahari springbok (72.1 – 74.7%; Hoffman *et al*., 2019)

Sex can affect the proximate composition of meat (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012). Male springbok had a lower IMF percentage than female springbok in all muscles (Table 6.1) and the IMF and moisture have a widely reported inverse relationship (Sebranek, 2014). This phenomenon has been noted in a variety of studies as reported in springbok from different regions (Hoffman, Kroucamp, & Manley, 2007), impala and kudu (L. C. Hoffman, Mostert, Kidd, & Laubscher, 2009) and beef (Browning, Huffman, Egberts, & Junst, 1990). However, higher fat percentage in the current study was not accompanied by a significant decrease in the moisture content (Table 6.1) as also shown by the low correlation (Table 6.2). It is argued that this low correlation is due to the low coefficient of variation between both the moisture and IMF contents. In fact, Namibian Kalahari springbok also did not have moisture differences between male and female springbok for the same muscles as the current study, although, there were no sex-related IMF differences either (Hoffman *et al*., 2019).

Springbok from different regions in South Africa also had higher IMF percentages for females in comparison to males (Hoffman, Kroucamp, & Manley, 2007; Van Zyl & Ferreira, 2004). This is due to female animals accumulating a higher degree of fat as a survival mechanism to aid in times of a higher degree of bodily stress such as lactation (Young, 1976). This phenomenon is seen in game/venison species such as roe deer (Hoffman *et al*., 2011), impala (Hoffman, Mostert, Kidd, & Laubscher, 2009; Hoffman, 2000; Hoffman, Kritzinger, & Ferreira, 2005; Van Zyl & Ferreira, 2004), kudu (Hoffman *et al*., 2009) and blesbok (Van Zyl & Ferreira, 2004). In contrast, red hartebeest did not differ for IMF percentage (Hoffman, Smit, & Muller, 2010), although age nor breeding season was not considered in this study. Mountain reedbuck (Hoffman, van Schalkwyk, & Muller, 2008) and kudu (Mostert & Hoffman, 2007) also did not differ between sexes for IMF percentage.

Protein differences in the current study were only found in the LTL when comparing sexes, where female springbok had a higher protein content for the LTL (Table 6.1). No sex-related protein differences were further reported in the current study; Van Zyl & Ferreira, (2004) and Hoffman *et al*. (2019) also found no differences in protein content between male and female springbok. The protein percentage of springbok meat from the current study (19.8 – 23.5 %) was similar to results reported by previous studies on Karoo springbok (Van Zyl & Ferreira, 2004) and Namibian (Kalahari) springbok (Hoffman, van Schalkwyk, & McMillin, 2019). The current study's protein content was also similar to the protein content reported for impala (Hoffman *et al*., 2009; Hoffman, 2000; Van Zyl & Ferreira, 2004), kudu (Hoffman *et al*., 2009; Mostert & Hoffman, 2007) and blue wildebeest (Van Heerden & Hoffman, 2018).

The chemical component ash generally makes up less than 1% of meat. This is generally comprising of minerals and vitamins but can also include carbohydrates (Huff-Lonergan & Lonergan, 2005). There were no differences in the ash percentage between subspecies or between sexes in the current study. The ash content of springbok meat ranges between 1.2 – 2.0 %. This is similar to ash values reported for springbok from different regions in South Africa (1.2 - 1.4 %; Hoffman *et al*., 2007) and from Namibia (1.1 – 1.3%; Hoffman *et* *al*., 2019). However, these were higher than values reported for springbok from the Karoo (6.3 – 6.4) by Van Zyl & Ferreira, (2004); it should be remembered though that in their study they reported the proximate composition of whole carcasses including the whole bone (and skin, etc.) which would have led to the higher ash contents. Springbok ash percentage of the current study tended to be similar to ash percentages as reported for impala (Hoffman *et al*., 2009), kudu (Hoffman *et al*., 2009) and ostrich (Majewska *et al*., 2009).

6.5 CONCLUSION

The drastic size and weight differences between Damara and Karoo subspecies makes the Damara subspecies an attractive option for South African game ranchers. Damara and Karoo subspecies did not differ in terms of moisture, protein, fat and ash contents. This implies that South African game ranchers can base springbok subspecies preferences on other economically attractive characteristics without nutritional composition detriment.

Female springbok had a higher IMF content than male springbok, and consequently, male springbok had a higher protein content than female springbok. Although significant, these IMF and protein differences were very minimal, and it is thus debatable whether the differences are of nutritive or marketable value/importance.

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CHAPTER 7
GENERAL CONCLUSION

The aim of this study was to determine the influence of subspecies (Damara vs Karoo), sex and intensity of culling on the carcass yield and meat quality of springbok (*Antidorcas marsupialis*). The Damara subspecies had a significantly larger size (measurements) and subsequently a significantly heavier dead weight and cold carcass weight, although dressing percentage between subspecies were similar. Sexual dimorphism is typical in mature springbok, where males had a heavier dead weight and cold carcass weights (Trial 1; Chapter 3). Damara springbok had heavier primal weights (neck, shoulder, front shank, ventral trunk, dorsal trunk, hind leg and back shank) as a consequence of their heavier carcass weight, but Damara and Karoo springbok had similar primal percentages as well as similar meat, bone and fat percentages of each primal (Trial 1; Chapter 4)

A high degree of intensity culling typically decreased the body size of the over-culled sex. This was seen in the lack of sexual dimorphism for dead weight and cold carcass weight between the Witsand springbok where the males had been selectively culled for the past decade. The consequence of the high intensity of culling is the decrease in the mean age of the male population and consequently, as there are few old males left, the remaining mature males have a smaller and lighter body in comparison to males from a herd that is rarely culled (Trial 2; Chapter 3). This discrepancy in ages between males from herds of different levels of intensity of culling further influenced the shoulder proportional percentage, as a higher proportion forequarter is a dominant (older) male trait that was not seen in the Witsand males when they were compared to the Wellington males (Trial 2; Chapter 4).

The larger Damara subspecies had a higher shear force and cooking loss percentage in comparison to the smaller Karoo subspecies, due to the differences in the cooling rate between subspecies as a factor of body size, ambient temperature and chilling conditions. Both subspecies had shear force values <33N, thus, their meat could be considered as tender. The differences between subspecies for physical meat quality were minor and would not necessarily negatively influence consumer perception. The Male springbok also had a higher shear force and cooking losses in comparison to females. This was possibly due to differences in collagen content and IMF between sexes (Trial 1; Chapter 5).

The degree of intensity of culling had minimal influence on the physical meat quality parameters except for shear force, where the Witsand springbok had lower shear force values than the Wellington springbok. This was mainly attributed to the difference in excitability between the springbok of the different farms. Both farm's meat was still below the benchmark of 33 N Warne-Bratzler shear force for very tender meat and differences in shear force would thus not negatively influence the consumer perception (Trial 2, Chapter 5).

The chemical composition did not differ between subspecies for any chemical component. Females as is generally typical in ruminant’s, had a higher IMF content than males, but did not differ from males for any other chemical component .Therefore, South African game ranchers can base springbok subspecies preferences on yield characteristics without nutritional composition detriment (Chapter 6).

Further research on the correlation of horn size and body weight as well as the influence of high intensity of selective culling on the horn growth could be conducted to establish baseline data of the negative implications that over-culling could have on a springbok herd. Sex, as was reported, influenced both the meat yield and meat quality in springbok, but the emergence of sexual dimorphism is age/maturity dependant. Further research on the carcass yield and meat quality at accurately determined ages for both male and female springbok, could better illustrate the differences between sexes in terms of yield and thus aide in the efficient management of meat production for springbok. Muscle fibre type greatly influences the meat quality and further research in the influence of muscle fibre type between subspecies on the meat quality of springbok would aide in the further quantification of the meat quality differences reported between subspecies.